

ELECTRICITY FORUM HANDBOOKS



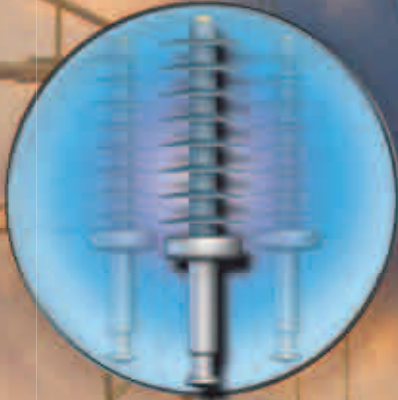
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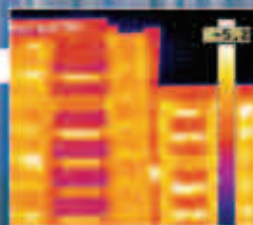
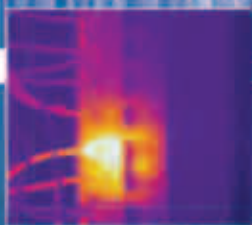
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The Electricity Forum
215 -1885 Clements Road
Pickering, Ontario L1W 3V4
Tel: (905) 686-1040 Fax: (905) 686 1078
E-mail: hq@electricityforum.com

The Electricity Forum Inc.
One Franklin Square, Suite 402
Geneva, New York 14456
Tel: (315) 789-8323 Fax: (315) 789 8940
E-mail: forum@capital.net

Visit our website at
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Publisher & Executive Editor

Randolph W. Hurst

Editor

Don Horne

Cover Design

Cara Perrier

Layout

Cara Perrier

Advertising Sales

Carol Gardner

Tammy Williams

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TABLE OF CONTENTS

Exploring the Necessity of the Hot Hipot Test <i>By Associated Research Inc.</i>	4
Line Leakage Testing: Is it Right for your Application? <i>By The Slaughter Company</i>	8
Comparative Corrosion and Current Burst Testing of Copper and Aluminum Electrical Power Connectors <i>By Ron Frank, Eng., Member, IEEE, Canadian Copper and Brass Association and Chris Morton, P.Eng., Member, IEEE, Powertech Labs Inc.</i>	11
How to Avoid the Real Cost of Non-Compliance in Static Control <i>By Newson Gale</i>	17
Understanding Insulation Resistance Testing <i>By AEMC Instruments</i>	19
10 Dumb Things Smart People do when Testing Electricity <i>By Fluke Corporation</i>	24
Isolation Technologies for Reliable Industrial Measurements <i>By National Instruments Corporation</i>	26
Inter-System Ground Noise: Cause and Effects <i>By American Power Conversion</i>	31
AC Motor Selection and Application Guide <i>By GE Industrial Systems</i>	34
Dielectric Withstand Testing of Modular and Manufactured Homes <i>By The Slaughter Company</i>	63
Why Calibrate Test Equipment? <i>By Fluke Corporation</i>	66
Reducing Ground Bounce in DC-to-DC Converters — Some Grounding Essentials <i>By Jeff Barrow</i>	68
Impedance/Return Loss: The Basics <i>By Paul Vanderlaan, Product Development Engineer</i>	73
How Stray Voltage Affects Multimeter Measurements <i>By Fluke Corporation.</i>	78
Whole Facility UPS Protection: A Practical Solution to Class-A Data-Center Power Densities <i>By Brad Roberts, PE, S&C Electric Company</i>	81
Ground Bond or Ground Continuity? Taking Your Customer's Safety to the Next Level <i>By The Slaughter Company</i>	83
Short Circuit Current Ratings & Solid State Relays <i>By Dr. Oscar Montero, Crydom, Inc.</i>	85
Buyer's Guide	88

EXPLORING THE NECESSITY OF THE HOT HIPOT TEST

Associated Research Inc.

INTRODUCTION

In an industry comprised of workers with varying electronics knowledge, a Hipot test can seem a daunting task for some. Indeed, many test operators and quality assurance supervisors, having never been trained in electrical engineering, have difficulty understanding the principles and setup of the test itself. Naturally, the mere mention of the more specific Hot Hipot test can bring about feelings of apprehension. Yet the concepts involved with the Hot Hipot test don't have to be entirely elusive to operator and engineer alike. In fact, with a basic understanding of a Hipot test setup it is relatively easy to understand, implement, and perform a Hot Hipot test.

HIPOT TEST THEORY

In order to understand what a Hot Hipot test is and how it is performed, it is first necessary to discuss the theory of the Hipot test itself. The Hipot test, sometimes called a Dielectric Withstand test, is used to verify the strength of the insulation between a product's current-carrying components and its chassis or enclosure. This is done by applying a high voltage from the mains-input lines to the chassis of the product and measuring the resulting leakage current flowing through its insulation. The theory: if a voltage much higher than the product would normally see is applied across the insulation without a breakdown (which results in an excessive amount of leakage current flow), the product will be able to operate safely when run under nominal operating conditions.

The Hipot tester is used to indicate whether or not a dielectric breakdown of the insulation has occurred by monitoring the leakage current resulting from the applied test voltage. Even under normal operating conditions, some leakage current will be present in any device under test (DUT), but at minute

and safe levels; however, when the insulation breaks down or is damaged an excessive amount flows to the chassis. This can present a substantial shock hazard to anyone that comes into contact with the product.

The Hipot test is so crucial because it is the best way to uncover workmanship and assembly defects in an electrical product that can lead to insulation breakdown.

Mistakes during assembly or faulty/damaged components exist to an extent in any manufacturing environment, and the Hipot test can uncover units that are unfit and dangerous to sell. Some of the defects which could result in insulation breakdown include: pinched insulation, pinholes, and poorly crimped wiring. In order to detect for breakdown in electrical products, this test is usually performed during the manufacturing process on 100% of all manufactured units, as well as during routine repair and maintenance.

HIPOT TEST SPECIFICATIONS

Hipot tests can be performed using either an AC or a DC voltage. Manufacturers may or may not be required to perform a specific type of Hipot test depending on the product and the standard to which it is being tested. Both AC and DC Hipot tests have inherent advantages and disadvantages that become evident depending on the characteristics of the DUT. The following table lists some of the basic advantages of each type of test:

These differences between AC and DC waveforms necessitate a variation in Hipot test procedures. Although the test is basically the same, the test operator needs to take into account the relationship between a DC waveform and its equivalent AC waveform. AC waveforms are often listed as RMS (root mean squared). This RMS value, known as the effective value, pro-

AC Hipot Advantages	DC Hipot Advantages
Slow ramping of the test voltage isn't necessary due to the changing polarity of the applied waveform.	The test can be performed at a much lower current level, saving power and with less risk to the test operator.
It is unnecessary to discharge the DUT after AC testing.	Leakage current measurement is a more accurate representation of the real current.
AC testing stresses the insulation alternately in both polarities.	DC testing is the only option for some circuit components: diodes, capacitors, ect.

vides a load with the same amount of energy as a DC waveform of the same voltage: a 25 volt DC source provides the same amount of effective energy as a 25 voltsrms AC source.

The actual quantitative value of the RMS AC waveform is much higher at the peaks of the sine wave. In fact, the difference between a peak AC waveform measurement and the RMS measured value is 1.414. The calculation is as follows:

$$\text{Voltsrms} * 1.414 = \text{Voltspeak}$$

Since a Hipot test stresses the insulation of a DUT with a high voltage, the applied test voltage must be the same value whether it is AC or DC. It is unnecessary to worry about the effective RMS value since the energy delivered to the DUT is of no importance; the peak (maximum) voltage is what we are concerned with.

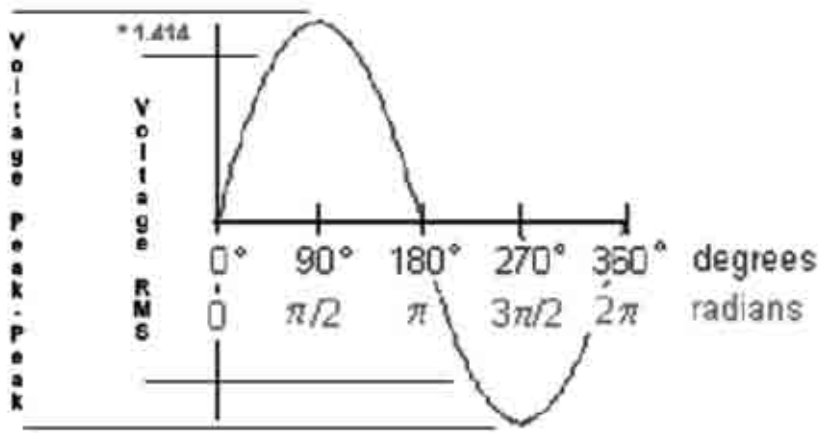


Figure 1.0: Peak vs. RMS Measurement of a Sinusoid

A good rule of thumb for determining the test voltage during an AC Hipot test is to multiply the nominal input voltage (usually from a wall outlet given as an RMS voltage) by 2 and add 1000 volts.

$$\text{AC Hipot test voltage} = \text{Nominal input voltage} * 2 + 1000$$

For a DC test use the following procedure to assure that the DC voltage is the same value as the peak of the AC wave-

form: multiply the calculated AC voltage by 1.414.

$$\text{DC Hipot test voltage} = \text{AC Hipot test voltage} * 1.414$$

By performing this operation, the DC voltage is applied at the same level as the peak of the AC voltage waveform.

The amount of time high voltage must be applied during testing is also specified in many safety agency standards. The most common test durations are 1 second for production tests and 1 minute for design tests. Further, agencies such as UL require that Hipot testers meet certain output voltage regulation specifications to ensure that the DUT is stressed at the correct voltage. Contact your local safety agency for more information about test duration and voltage requirements.

HIPOT TEST PROCEDURE

The Hipot test is set up by connecting the two output leads of the tester to the device under test. Follow the steps below to ensure that your tester is properly connected.

1.) For products terminated in a three-pronged line cord (known as Class I products) or a two-pronged line cord (known as Class II products), connect the hot lead of the Hipot tester to both the line and the neutral inputs to the DUT.

2.) Place the DUT's power switch to the ON position.

3.) Connect the return lead of the Hipot tester to the metal chassis or enclosure of a Class I DUT.

4.) For a Class II product, connect the return lead of the tester to a piece of aluminum foil that is wrapped around the chassis of the DUT. The aluminum foil is necessary to create a conductive material around the insulation which comprises the chassis of a Class II product.

*By connecting the tester in this way, all of the internal current-carrying conductors are raised to the same potential with respect to the chassis. This connection scheme ensures that the high voltage waveform is applied directly across the insulation of the product.

HIPOT TEST SHORTCOMINGS

The Hipot test has long been considered the most important electrical safety test; as such it is usually specified by safety agencies to be performed on all consumer and industrial products terminated in three- or two-pronged line cords. Historically this test has been effective on the gamut of electrical products due to a dependence on single-pole relays and mechanical switches. Yet products that operate off of a 220 volt input often incorporate double-pole relays that open both sides (line and neutral) of the input line.

Further, with the dawn of the digital age we now find that many products incorporate electronic switches. Often these switch-

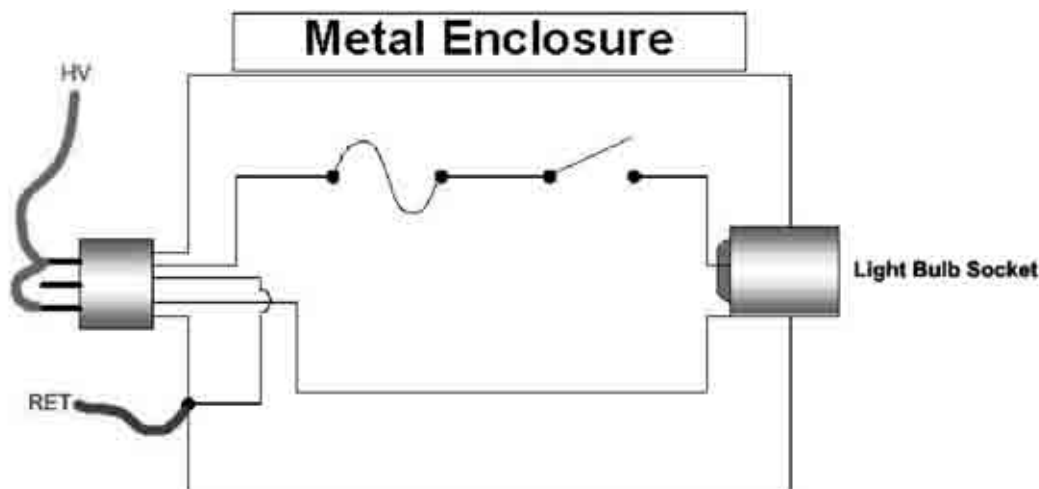


Figure 2.0: Hipot Test Connection Diagram

es and relays cannot be closed manually without powering-up the product under test. In these cases a standard Hipot test becomes ineffective.

With both sides of the line open the Hipot tester cannot energize all the current carrying conductors within the DUT and the test results become invalid. The only way to perform a valid Hipot test on products that contain these types of relays or electronic switches is to energize the product while the Hipot test is being performed. Yet in order to Hipot test a powered product, special steps must be taken since, under normal conditions, the line and neutral inputs of the DUT would be shorted together. This modified setup is commonly called a "Hot Hipot test".

HOT HIPOT TEST PROCEDURE

A Hot Hipot test is performed in the same fashion as a standard Hipot test. The primary difference is the addition of 1 piece of equipment, an isolation transformer. This transformer is used to isolate the input power to the DUT from earth ground. Without the use of this type of transformer, the chassis of the DUT, which is usually grounded, would be directly connected to the return of the Hipot tester (which is also referenced at or near ground potential). The return of the Hipot tester usually sees current in the milliamp range; however, without an isolation transformer, the Hipot tester could be exposed to several amps of line current flowing back through its return. This could cause damage to the tester as well as create a possible shock or fire hazard during a Hot Hipot test.

The isolation transformer creates the necessary isolation between the input lines of the DUT and the Hipot tester. Of course, an AC test voltage is necessary for this test since DC waveforms don't work with transformers. It is also important to verify that the isolation transformer is rated to handle the applied Hipot test voltage; this will prevent damage to the transformer.

- 1) In order to set up the test correctly, the primary side of the isolation transformer should be plugged into the power source used to provide the input power to the device under test.
- 2) The secondary side of the transformer should then be connected to the input of the DUT.
- 3) Once connected, the Hipot tester may then be plugged into a standard wall outlet.
- 4) The hot lead of the Hipot tester should then be connected to the output of the secondary side of the isolation transformer. By doing this, you are connecting the hot lead of the Hipot in between the isolation transformer output and the line side input of the DUT.
- 5) The return lead of the Hipot tester should then be connected to the chassis of the DUT.
- 6) Once the setup is completed, you may turn on the Hipot tester and the DUT.
- 7) Perform the test as you would a standard Hipot test.

Hot Hipot Tester

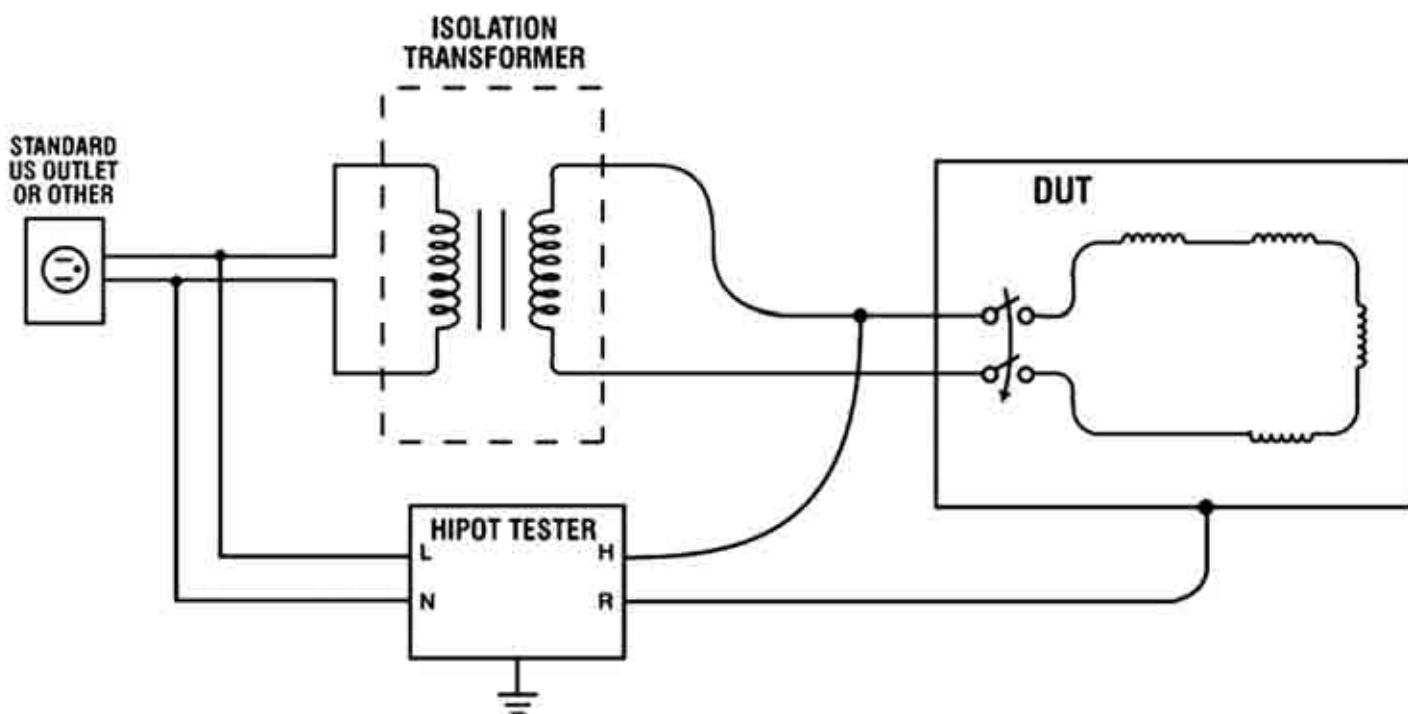


Figure 3.0: Hot Hipot Test Connection Diagram

SUMMARY

With the advancement of the electronics industry Hot Hipot testing is becoming more and more common during routine production line testing. Products that were once operated solely through the use of mechanical relays and switches are now being controlled via electronic circuits that can only be energized while the product is running.

Still other products that use 220 volt inputs contain relays that open both sides of the line, rendering a standard Hipot test ineffective. Whatever the reason, a working knowledge of the Hot Hipot test makes good sense of anyone working in the quality assurance or safety testing fields.

Although the Hot Hipot test has long been considered a mysterious and complex safety test, in actuality it isn't much more difficult to perform than a standard Hipot test.

With an understanding of the basic test procedure involved in performing a Hipot test and possession of the right equipment, a Hot Hipot test can be performed safely and efficiently. Paying attention to careful setup and implementation, a test operator, quality assurance supervisor, or engineer alike can feel comfortable performing a Hot Hipot test on a variety of products.

LINE LEAKAGE TESTING: IS IT RIGHT FOR YOUR APPLICATION?

The Slaughter Company

INTRODUCTION

The Line Leakage test (LLT for short) is most often specified to be performed as a type test in a design or engineering laboratory or as a routine production line test on medical devices right before they ship. Not as commonly performed as a Dielectric Withstand or Ground Bond test in a production environment, LLT can cause some confusion for engineers & technicians alike.

However, technological advancements have begun to lessen the outward complexity of the test.

What used to be complicated set-ups and testing procedures has now been simplified with the use of multi-function testing instruments. For instance, all-in-one testing solutions such as our 6330 now come equipped with the components and relay switching networks to perform leakage tests in an automated sequence with little or no input from the test operator. This makes for safer and more efficient testing.

Electrical products including anything from appliances to handheld tools, must be tested during the design and development phase in order to receive a safety agency listing. In these laboratory environments, the LLT is used to help ensure that the product's manufacturing processes and assembly practices are satisfactory. Along with other common tests such as the Hipot and Ground Bond tests, the Line Leakage test is used in this situation primarily as an indicator of design quality.

Some products, such as medical equipment, are designed with the intention of direct contact with a patient. Line Leakage tests should be performed on these products as a 100% routine production line test. Due to the sensitive nature of the applications for which this type of equipment is used, it is easy to see why rigorous testing must be performed as a routine test.

Whether the LLT is being performed as a type test or as a production test, the purpose of the test is the same: to determine if a product's insulation has the integrity to prevent any current from reaching the operator. When current does find its way through or across any part of a product's insulation system, it is known as leakage.

There are several methods manufacturers employ to prevent leakage, such as utilizing reinforced or double insulation systems and providing sufficient spacing between current-carrying conductors. Despite these measures, leakage current will be present in every product to some degree. Indeed, the electrical relationships between the very materials used in a product's construction are what account for a substantial portion of any resulting leakage. While the resistance of the insulation will account for some leakage, using an insulating material in between conductors creates a certain amount of distributed capacitance which helps to facilitate leakage to

ground. This current will look to travel through a product's insulation system and return to ground by any means available, whether that is through a safety earth ground connection, or through an operator who is at ground potential.

For example, medical devices that run off of line power have components that are in direct contact with a patient. In this case a wall outlet, an almost unlimited power source, has a direct connection to a patient who could already be sick or frail. It is of vital importance in this scenario that the leakage current produced by the product be small enough so as not to be perceived by the individual to whom the device is connected. More importantly, the insulation of the device needs to have the integrity to prevent any current from reaching the patient.

A CLOSER LOOK AT THE LINE LEAKAGE TEST

The Dielectric Withstand (Hipot) test or Insulation Resistance (IR) test are common safety tests performed in both production line and lab environments. These tests do a good job of determining whether a product is manufactured correctly with good insulation, but they don't tell us how much leakage current could be flowing through a product while it is running. Furthermore, these tests cannot tell us how that leakage current might change under different conditions. There is no way to determine what might happen if the product is connected to a power source incorrectly, if the operator plugs the product into an outlet that is wired incorrectly, or if the neutral side of the line opens up. The Line Leakage test was developed as a way of determining how leakage current would act conditions such as these.

The Line Leakage test is actually a general term that is used to describe a series of tests. There are 4 different types of LLT's: Earth Leakage test, Enclosure Leakage test, Patient Leakage Current test, and Patient Auxiliary Current test (we will discuss each type of test later in the document). Each test is performed under nominal operating conditions as well as in a variety of fault conditions. These fault conditions provide us with valuable information about how a product's leakage current will behave if operated incorrectly.



Figure 1.0: Model 6330 6-in-1 Electrical Safety Tester (including LLT)

While the test setup may vary from test to test, the actual test methodology doesn't change. One-box solution testers such as the our 6330 come equipped with the components and relay switching networks to perform all Leakage tests in an automated sequence with little or no input from the test operator. The 6330 also has the capability to record leakage using Peak or RMS measurements, a feature beneficial for manufacturers who must comply with standards such as IEC 60990. (See Figure 1).

MEASURING DEVICES

Since the LLT is designed to measure the leakage current of a product while it is running, the way in which the current is measured is of vital importance. Therefore, Line Leakage tests incorporate measuring devices (MDs), which simulate the impedance of the human body. The placement of the measuring device is the factor that distinguishes one type of LLT from another. Measuring devices are specified by safety agencies depending on product classification and the standard to which the product is being tested. For the most part, MDs are resistive and capacitive networks designed to simulate the impedance of the human body in certain conditions. In most of today's testers, these measuring devices are incorporated in the circuitry of the tester.

During Line Leakage tests for example, MDs can be used to approximate full hand-to-hand or hand-to-foot contact. Figure 2.0 shows the network that should be used when testing to EN60601-1.

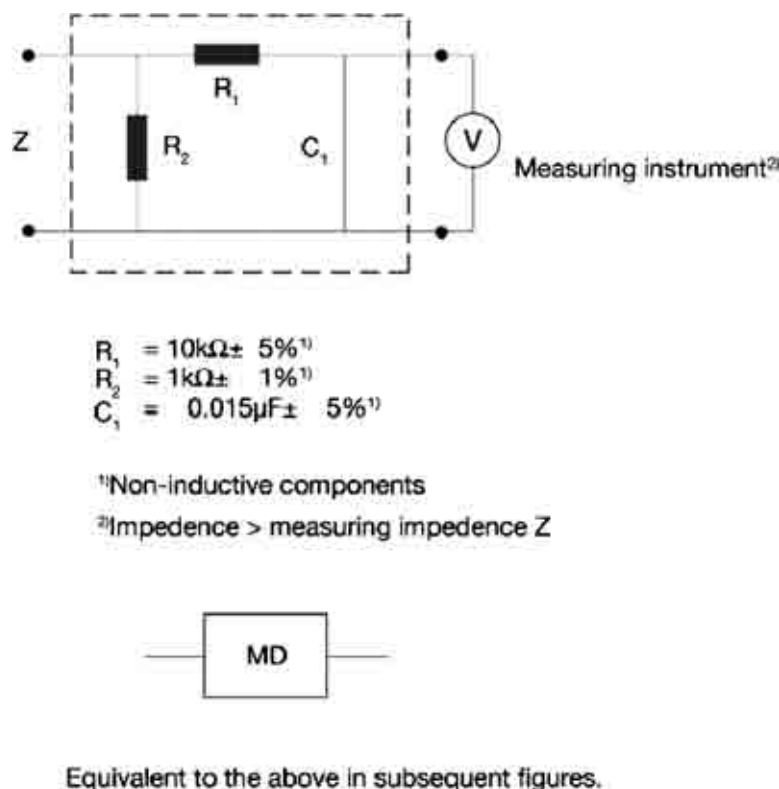


Figure 2.0: MD Schematic for EN60601-1

Many safety agencies differ in their interpretation of how the test's MD should be configured. Regardless of where the MD is placed or how it is configured, the test should measure how much leakage current would flow through a person if they were to come into contact with the device under test (DUT). Below is an example of an internal switching network that may be found in a Line Leakage Tester.

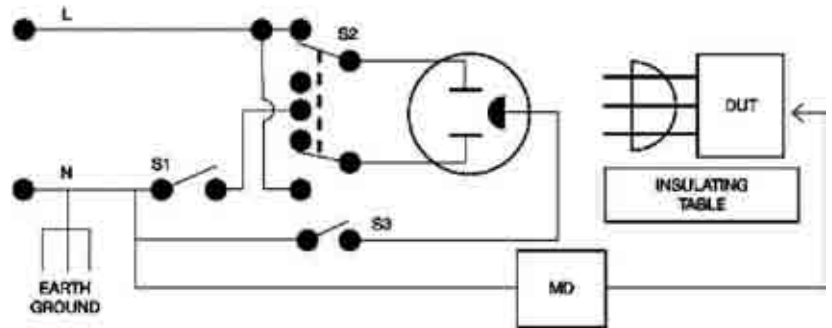


Figure 3.0: 6330 Internal Switching Network

In this internal switching network the MD can be any one of 8 built-in measuring devices as specified by safety agency standards. Relays S1, S2, and S3 are used to simulate the various fault conditions during testing. S1 corresponds to the open neutral condition, S2 to the reversed polarity condition, and S3 to the open ground condition.

FAULT CONDITIONS

The LLT is performed in both normal and single fault operating conditions. Measuring leakage current during fault conditions is important in order to determine if a product fails "safely", if it fails at all. A product that fails safely will not produce excessive leakage current even if one of the following combinations of fault conditions occurs. Table 1.0 below shows the various combinations of relay closures that will simulate up to 8 total testing scenarios.

TEST SETUP AND PROCEDURE

EARTH LEAKAGE TEST

The Earth Leakage test places the MD from the earth ground pin of the DUT to the neutral side of the line (which is referenced to ground). In this configuration, power is applied to the DUT at 110% of the nominal voltage level using an isolation transformer. The MD is used to measure the amount of leakage current flowing from the mains-input line and returning to ground through the product's insulation under normal and single fault conditions.

ENCLOSURE LEAKAGE TEST

The Enclosure Leakage test places the MD from one or more points on a DUT's chassis to the neutral side of the line. In this configuration, power is applied to the DUT at 110% of the nominal voltage level using an isolation transformer. The MD is used to measure the amount of leakage current flowing from the enclosure, excluding applied parts accessible to the operator or patient to ground or to another part of the enclosure

Neutral (S1)	Polarity (S2)	Ground (S3)
OPEN	NORMAL	OPEN
OPEN	REVERSED	OPEN
OPEN	NORMAL	CLOSED
OPEN	REVERSED	CLOSED
CLOSED	NORMAL	OPEN
CLOSED	REVERSED	OPEN
CLOSED	NORMAL	CLOSED
CLOSED	REVERSED	CLOSED

Table 1.0: Line Leakage Test Fault Conditions

under normal and single fault conditions.

APPLIED PART LEAKAGE TEST

The Applied Part Leakage test, also known as the Patient Leakage test places the MD from a patient-applied part (usually some sort of probe or meter that comes into direct contact with a medical patient's body) to the neutral side of the line. In this configuration, power is applied to the DUT at 110% of the nominal voltage level using an isolation transformer. The MD is used to measure the amount of leakage current flowing from applied part to ground under normal and single fault conditions.

PATIENT AUXILIARY LEAKAGE TEST

The Patient Auxiliary Leakage test places the MD in between 2 different applied parts that come into contact with a patient's body. In this configuration, power is applied to the DUT at 110% of the nominal voltage level using an isolation transformer. The MD is used to measure the amount of leakage current flowing from one applied part to another under normal and single fault conditions.

CONCLUSION

Although the Line Leakage test can seem somewhat confusing at times, it is an important test that should be given due consideration in any electrical safety testing routine. Technological advancements have made LLT much easier to perform and more manufacturers are performing LLT in both a lab and production environment. With some research and the right equipment, Line Leakage testing can be performed as quickly and easily as more common tests such as a Hipot or Ground Bond test. This means that the LLT can be added to a safety testing routine, without negatively impacting throughput and the addition of the LLT to any safety testing routine will help make electrical products safer and more reliable. This will save money in the long run.

COMPARATIVE CORROSION AND CURRENT BURST TESTING OF COPPER AND ALUMINUM ELECTRICAL POWER CONNECTORS

Ron Frank, Eng., Member, IEEE, Canadian Copper and Brass Association and Chris Morton, P.Eng., Member, IEEE, Powertech Labs Inc.

Abstract — Crimped and mechanically bolted aluminum and copper connectors are commonly used for terminating industrial electrical power cables with ratings up to 600 V. Aluminum connectors are available for use with aluminum or copper conductor, and copper connectors are available for use with copper conductor only.

The performance of copper and aluminum connectors was compared by conducting accelerated aging under corrosive environmental conditions. The testing consisted of 2,000 hours of cyclic salt fog environmental exposure, in conjunction with periodic electrical current burst testing. The connectors were evaluated by comparing the change in resistance of the test samples as the test progressed.

I. INTRODUCTION

For industrial and commercial applications, crimped and mechanically bolted aluminum and copper connectors are commonly used for terminating power cables. Copper connectors are available for use with copper conductor, and aluminum connectors are available for use with copper and aluminum conductor. Test standards for power connectors include CSA C57 and ANSI C119.4 500-cycle current cycling tests, which are intended to establish long-term performance.

There are significant differences in the material and electrical properties of aluminum and copper and their oxides, which may affect their long-term performance.

Aluminum oxidizes readily when exposed to air, and a strongly attached, hard outer layer of electrically insulating oxide quickly forms around the metal. For this reason, aluminum connectors are usually manufactured with a tin coating which is intended to prevent surface oxidation of the connector from occurring. Aluminum crimp connectors are also pre-filled with oxide inhibiting compound to reduce oxidation between the conductor and connector when in service. Aluminum conductors must always be wire brushed to remove the oxide layer, and oxide-inhibiting compound is immediately applied to reduce oxidation.

Copper also oxidizes when exposed to air, but the oxide that forms is relatively soft and conductive, although not as conductive as the base metal. For this reason, copper connectors can often be installed without oxide inhibitor. Wire brushing of the conductor, although recommended, is not as critical as with aluminum. Copper connectors are often manufactured with a tin coating to reduce surface oxidation and discolouration, but they are also available without tin coating.

When copper and aluminum are brought into direct contact in the presence of moisture, a strong galvanic reaction takes

place due to the dissimilar properties of the metals. For this reason, aluminum connectors are not used with copper conductor unless an interface material that is more compatible with both copper and aluminum is present, such as tin.

However, tin is also susceptible to oxidation, and if the tin layer is compromised, then galvanic corrosion between the base metals can still occur.

The differences in properties of copper and aluminum may result in a significant performance difference in the various types of electrical connectors when in long-term service.

II. OBJECTIVE

The objective of this study was to compare the contact resistance at the junction between the connector and conductor under harsh environmental laboratory testing conditions for the following material combinations:

- copper connectors on copper conductor,
- aluminum connectors on copper conductor, and
- aluminum connectors on aluminum conductor.

The connectors, conductor, and oxide inhibitor used to make the samples were standard commercially available varieties obtained from several different manufacturers.

Manufacturer names are omitted from this paper since the intention of the study was not to compare specific manufacturers' products. A variety of commonly available products were used so that general conclusions could be drawn.

III. TEST SAMPLES

The test samples used in the study were combinations of copper and aluminum conductors and connectors, with all components being standard off-the-shelf varieties. Copper conductor was bare 19-strand 2/0 AWG, and aluminum conductor was 18-strand compact 4/0 AWG. Conductor sizes were selected to be approximately the same ampacity. Connectors were a combination of compression and mechanical bolted type 1-hole lug connectors, with a total of ten connectors of each material combination used. All aluminum compression connectors were tin plated and supplied pre-filled with oxide inhibitor. A list of the test samples is provided in Table I, and a photograph of the samples as received is shown in Fig. 1.

Sample Nos.	Connector Material	Conductor Material	Connector Information			
			Type ^a	Manufacturer	Size (AWG or MCM)	Plating
A1, A2	Al	Al	Mech.	A	#6-250	Tin
A3, A4	Al	Al	Comp.	A	4/0	Tin
A5, A6	Al	Al	Comp.	B	4/0	Tin
A7, A8	Al	Al	Mech.	C	#6-250	Tin
A9, A10	Al	Al	Comp.	D	4/0	Tin
B1, B2	Al	Cu	Comp.	D	2/0	Tin
B3, B4	Al	Cu	Comp.	C	2/0	Tin
B5, B6	Al	Cu	Comp.	A	2/0	Tin
B7, B8	Al	Cu	Mech.	C	#6-250	Tin
B9, B10	Al	Cu	Mech.	A	#6-250	Tin
C1, C2	Cu	Cu	Comp.	D	2/0	Tin
C3, C4	Cu	Cu	Comp.	C	2/0	Tin
C5, C6	Cu	Cu	Comp.	A	2/0	Tin
C7, C8	Cu	Cu	Mech.	C	#6-250	None
C9, C10	Cu	Cu	Mech.	A	#2-4/0	None

a. Mech.=mechanical, Comp.=compression

TABLE I. CONNECTOR SAMPLES USED FOR THE TESTING



Figure 1. Connector samples used for corrosion and current burst testing

A. CONNECTOR INSTALLATION PROCEDURES

Connectors were installed according to the manufacturer's recommendations. This included wire brushing the conductor, applying an off-the-shelf oxide inhibitor (for aluminum mechanical connectors only), and crimping of the compression connectors using a standard manual crimping tool. No oxide inhibitor was applied to any of the copper-to-copper connections. Mechanical connectors were installed using torque levels appropriate to the screw size in the clamping mechanism of the connector.

B. CONNECTOR SAMPLE ASSEMBLIES

Each connector sample was installed on approximately 0.5 m of conductor, with a current equalizer on the end of the conductor opposite each connector. The equalizer was intended

to provide a solid electrical connection to each strand of the conductor, so that current could be applied uniformly to the conductor. Welded aluminum equalizers were used on the aluminum conductor, and brazed copper equalizers were used on the copper conductor. Three groups of 10 samples each were connected together back-to-back to form three series circuits, which were labeled as sample sets 'A' (all aluminum), 'B' (copper conductor with aluminum connectors), and 'C' (all copper). A photograph of a complete connector assembly, with 10 connectors and equalizers, is shown in Fig. 2. Control conductors were subjected to the corrosion and current burst testing along with the connector and conductor samples. These consisted of 1 m lengths of copper and aluminum bare conductor with no connector attached.

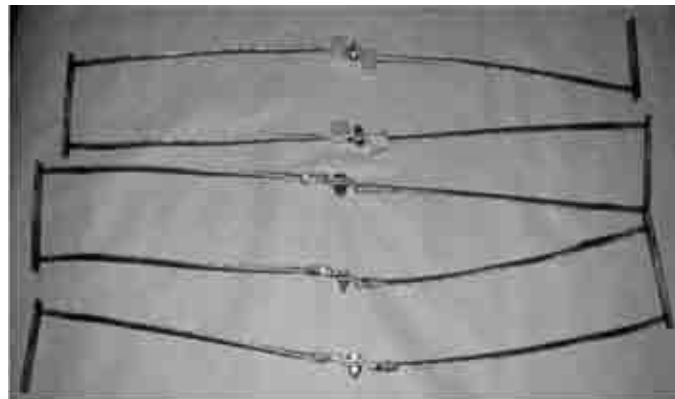


Figure 2. Connector sample assembly with equalizers and conductor (copper conductor with aluminum connector samples shown).

IV. TEST PROCEDURES

The testing consisted of periods of corrosive environmental exposure, followed by application of high current. This was intended to produce conditions in which connectors that were susceptible to corrosion showed an increase in contact resistance as the testing progressed.

The cyclic testing was conducted in the following sequence:

- Salt fog corrosion cycling was carried out for 500 hour blocks of time.
- Current burst tests were carried out following each 500 hour salt fog period.
- DC resistance readings of each connector were made approximately every 170 hours during the corrosion testing, and before and after each set of current burst tests.
- A total of four sets of salt fog and current burst tests were conducted, for a total of approximately 2,000 hours of salt fog testing.

A. CORROSION CYCLING

Connector sample groups were arranged on a three-tier PVC rack in an environmental chamber with the conductors and connectors oriented horizontally, and the connectors suspended in clear air. The positions of the connector sets were exchanged periodically so that consistent environmental exposure from sample to sample was achieved over the testing period.

Each 4 hour corrosion testing cycle consisted of the following steps:

- Salt fog spray for a period of 1 hour 45 minutes, consisting of a fine mist of aerated 3% NaCl solution buffered to a pH of 5.5 using nitric acid.

- Dry heat for a period of 2 hours, reaching a maximum of 70°C during the 2 hour period.
- Clear water rinse for a period of 15 minutes.

B. CURRENT BURST TESTING

The reason for conducting current burst testing was to encourage accelerated degradation at the connector contact with the conductor. For the test, current levels of 1750 Arms for 4/0 aluminum conductor, and 1800 Arms for 2/0 copper conductor were determined to be sufficient to produce the desired effect. For each test, the current was held at the required level long enough to raise the temperature of the control conductor to 250°C, as determined by a thermocouple measurement at the center of the control conductor span.

Typically, this required an application of current for approximately 50 seconds, starting with a conductor at near room temperature. The calculation to determine these levels is described in detail in Appendix A.

Samples were subjected to current burst testing as follows:

- Each set of 10 connectors, which were joined together in series, were subjected to current burst testing simultaneously.
- The control conductor was placed in series with the connector assembly. A thermocouple was attached to the center of the length of each control conductor to measure the conductor temperature during current burst testing.
- Five short duration bursts of high current were applied in succession. The control sample was allowed to cool to 40°C or less between each current burst.

The contact resistance of each connector was measured at room temperature using a micro-ohmmeter before and after each set of five current burst tests.

C. DC RESISTANCE MEASUREMENTS

All contact resistances were measured on dry samples at room temperature (20°C) using a LEM model D3700 microohmmeter.

Since resistances were all measured at the same temperature level, no correction was applied.

Resistances were measured from the equalizer to the body of the connector, so that an average reading was obtained for each connector. Four point resistance measurements were made to eliminate lead resistance errors, and measurements were made at a current level of 10 A DC.

V. TEST RESULTS

A. RESISTANCE MEASUREMENTS

1) Raw Test Data: Bar charts showing all of the measured resistances during the testing are shown in Fig. 3 through Fig. 5. The resistance values are displayed in chronological order from left to right, so that the left-most bar is the reading before testing, and the right-most bar is the reading after 2000 hours of environmental exposure and final current burst testing.

2) Aluminum Equalizer Failure and Corrected Results:

During the last set of current burst tests (after 2000 hours of corrosion cycling), a problem with the welded aluminum equalizers became apparent when one of the equalizers, on sample no. A7, was damaged by excessive heating during the first current shot. It appeared that some of the welded aluminum equalizers were being excessively degraded by the environmental exposure.

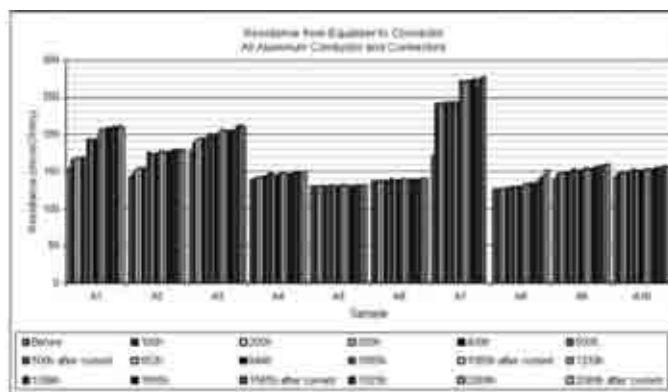


Figure 3. Resistance measurements for all-aluminum connections (Group A).

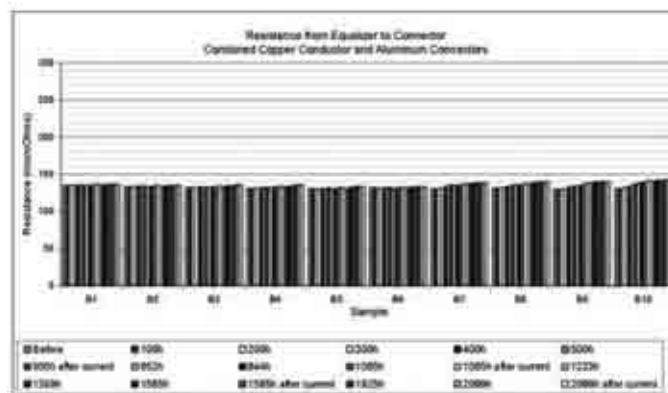


Figure 4. Resistance measurements for aluminum connectors on copper conductor (Group B).

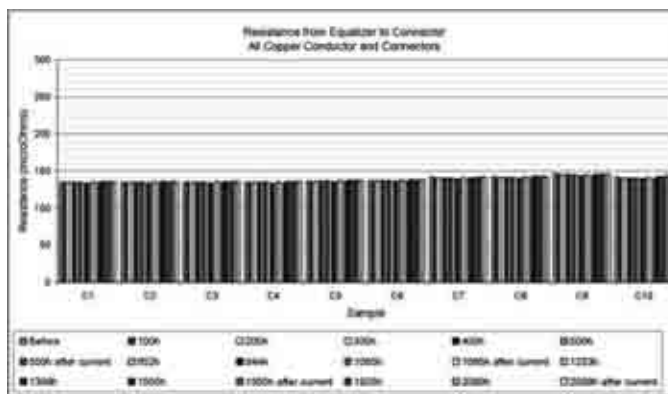


Figure 5. Resistance measurements for all-copper connections (Group C).

A current distribution measurement was necessary to confirm which equalizers had probably sustained damage. The current distribution was determined by measuring the voltage drop over a fixed distance on each of the 11 outer strands with a fixed DC current of 10 A applied to the entire conductor from equalizer to connector. The equalizers with a small variation between voltage readings were assumed to have had an evenly distributed current, which indicated that the equalizer and connector were still making a consistent connection. The equalizer/connector groups with a large variation in voltage had either a poor connection at the equalizer, a poor connection at the connector, or both. A graph of the measured voltage values which

have been normalized to the average reading for each equalizer is shown in Fig. 6. The results indicated that samples A1, A3, A7, A8, and A10 had a poor current distribution, and were suspected of being damaged. For these samples, the old equalizer was cut off, the conductor was thoroughly cleaned and wire brushed, and a new equalized connection was made using a new aluminum compression connector. The equalizer-to-conductor resistances were then re-measured for these samples, and a small correction was made to compensate for the amount of conductor that was cut off. The new values were used as the final resistance readings.

A graph with the corrected measured resistances of the aluminum connectors with re-made equalizers is shown in Fig. 7. For the connectors with re-made equalizers, since the only valid readings were made at the beginning and end of the test, all other readings were omitted.

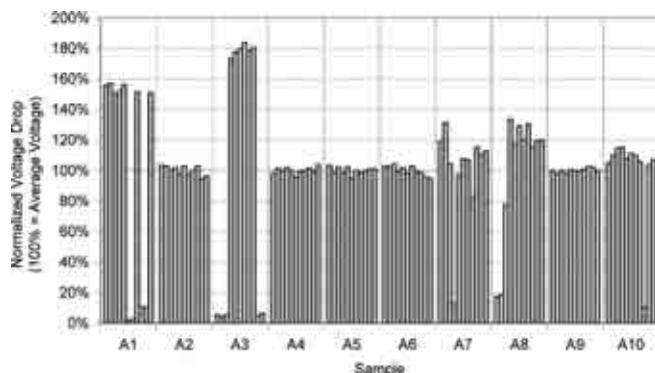


Figure 6. Current distribution measured by voltage drop along the conductor outer strands. Results were normalized to the average voltage for each equalizer.

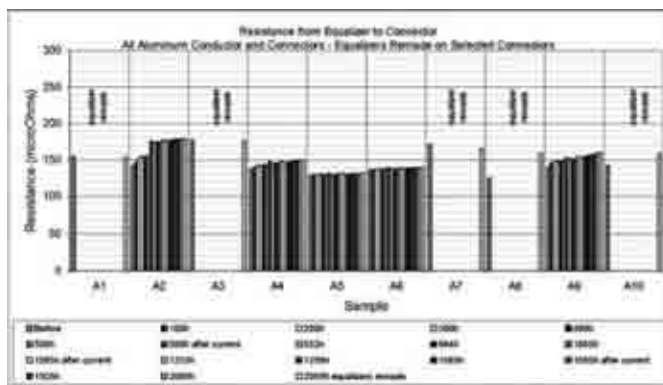


Figure 7. Corrected resistance measurements for all-aluminum connections (Group A).

B. CONNECTOR APPEARANCE

1) Aluminum Connectors: The aluminum connectors on both the aluminum and copper conductor showed a considerable amount of surface corrosion after testing, and a build-up of white oxidation. On some of the mechanical connectors, the tin plating had flaked off the surface and the underlying aluminum showed signs of corrosion. Photographs of the all-aluminum connectors before and after testing are shown in Fig. 8, and the aluminum connectors on copper conductor are shown in Fig. 9.

2) Copper Connectors: The copper connectors had a duller finish after the testing and showed some signs of surface

oxidation, but the tin plating was intact (where present).

Photographs of the all-copper connections before and after testing are shown in Fig. 10.

VI. DISCUSSION

The measured resistance values are made up of a combination of the equalizer resistance, conductor resistance, and connector contact resistance. Since the conductor resistance dominates, even significant changes in the connector contact resistance may not result in a large change in the overall resistance reading. By calculating the resistance readings during the testing as a percentage of the initial resistance reading, the overall effect can be more easily seen.

Fig. 11 shows the percent change in resistance for all connectors, measured after each current burst test.

On average, the before-test equalizer-to-conductor resistance readings were approximately 145uΩ for the aluminum conductor samples, and 135uΩ for the copper conductor samples. Initial contact resistance readings from the conductor to the connector were measured at approximately 10-15uΩ, or approximately 10% of the total resistance reading.

Assuming that most of the change in resistance during the test is due to an increase in connector contact resistance, then an increase in equalizer-to-conductor resistance of 10% would correspond to an increase in connector contact resistance of over 100%. On this basis, an increase in the equalizer-to-conductor resistance of 5% may be considered to be significant, and an increase of 10% or more may be considered to be a failure of the connector.

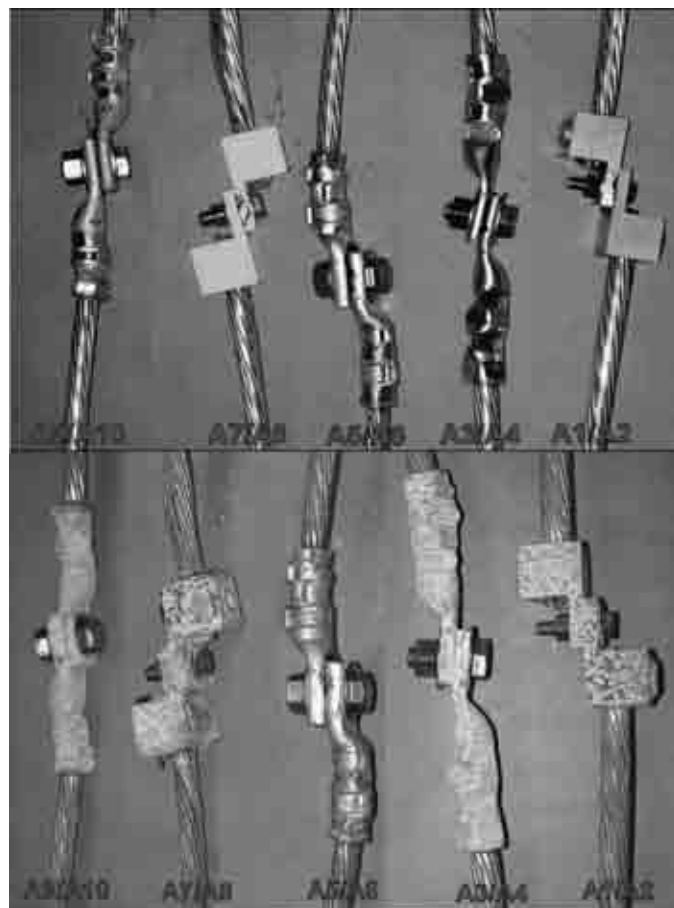


Figure 8. All-aluminum connections before testing (top) and after 2000 hours of environmental testing (bottom).

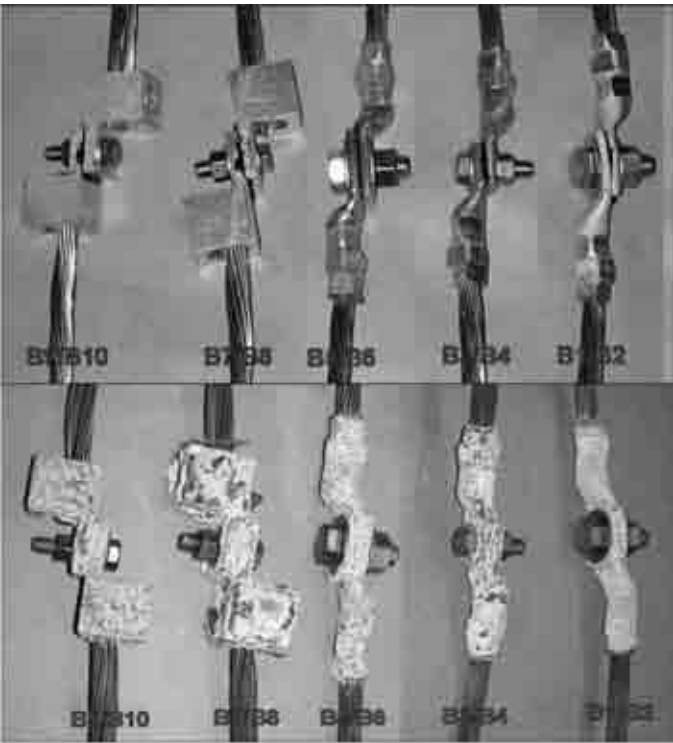


Figure 9. Aluminum connectors on copper conductor before testing (top) and after 2000 hours of environmental testing (bottom).



Figure 10. All-copper connections before testing (top) and after 2000 hours of environmental testing (bottom).

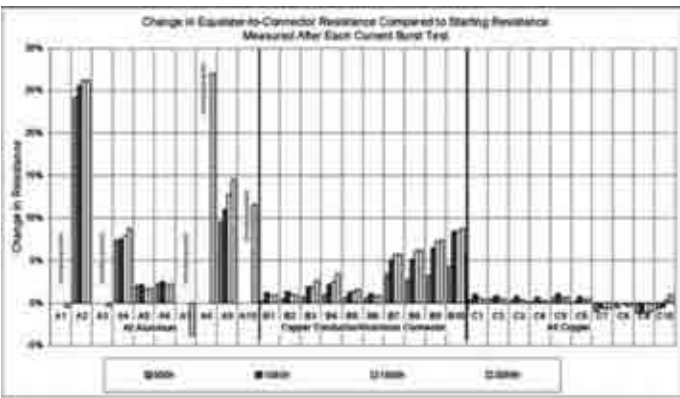


Figure 11. Percent change in resistance for all connectors compared to the resistance before testing, measured after each set of current burst tests.

The final results of the corrosion and current burst testing are given in Table II, which shows the number of samples of each type listed by percent change in resistance over the entire testing period.

Connector Type	Conductor Type	Overall resistance change compared to starting resistance:				
		-5% to 0%	0% to +1%	+1 to +5%	+5% to +10%	>+10%
Al	Al	3	0	2	1	4
Al	Cu	0	3	3	4	0
Cu	Cu	3	7	0	0	0

Table II. Number of samples of each type listed by percent change in resistance during the test

VII. CONCLUSIONS

The overall results for each connection type may be summarized as follows:

- A. Aluminum connectors on aluminum conductor:
 - 40% of the connector samples could be considered to have failed (>10% increase).
 - 10% of the samples showed a significant increase in resistance (5% to 10% increase).
 - 20% of the samples showed a moderate increase in resistance (1% to 5% increase).
 - 30% of the samples showed a decrease in resistance.
- B. Aluminum connectors on copper conductor:
 - 40% of the samples showed a significant increase in resistance (5% to 10% increase).
 - 30% of the samples showed a moderate increase in resistance (1% to 5% increase).
 - 30% of the samples showed a decrease in resistance.
- C. Copper connectors on copper conductor:
 - 70% of the samples showed a small increase in resistance (0% to 1% increase).
 - 30% of the samples showed a decrease in resistance.

The best performance in this 2000 hour corrosion and current burst test was attained by the all-copper connectors, which showed very little sign of degradation in electrical performance.

APPENDIX A

DETERMINATION OF CURRENT BURST LEVEL

A mechanical or compression high current connection relies on good asperity contact at the connection interface to maintain a low contact resistance. Asperity contact is maintained by the residual contact force on the connector, which is supplied by the screw fitting in a mechanical connector, or the residual stress in the deformed metal in a compression connector.

Under corrosive conditions, a poor connection may build up insulating oxides in the spaces between the asperities and at the edges of the asperities. High level, short duration current bursts are applied to the samples for sufficient duration to produce elevated temperatures at the asperity interface between the connector and conductor. The intention is to produce softening or melting of the asperities at the interface during the test. In a connector which has a build up of oxides, softening or melting at the asperities may cause loss of asperity contact if the residual force on the connector is insufficient to re-establish asperity contact with the oxide layer present. In an oxide free connection, the residual force can actually improve asperity contact when the asperities soften, resulting in a lower contact resistance.

The objective is to apply current bursts at a level which produces interface melting in a contact which has a high enough resistance to result in interface softening in the standard CSA C57 500-cycle connector test [4]. Therefore, the current pulse level is determined as follows.

According to Holm [2], the voltage drop across a contact is given by the following relation.

where:

$$U_p^2 = 4L(T_I^2 - T_B^2) \quad (1)$$

U_p = peak voltage drop across contact

L = independent constant $2.4 \times 10^{-8} \text{ V}^2\text{K}^{-2}$

T_I = absolute temperature (K) of the contact spots in the interface

T_B = absolute temperature (K) of the bulk of the connector

A bulk temperature of 100°C is used in the calculation, which is the maximum control conductor temperature used in the C57 cycling test. The RMS voltage, U_{rms} , is obtained by dividing the peak voltage by $\sqrt{2}$.

The magnitude of the current, I , required to produce either softening or melting at the interface is given by:

where:

$$I = U_{rms}/R \quad (2)$$

R = resistance at which either interface softening occurs in the C57 test, or melting occurs in the current burst test.

The current burst levels calculated are given in Table III.

The calculation indicates that current levels of approximately 1800 Arms and 1750 Arms are suitable for copper and aluminum respectively.

Conductor Size	Conductor Material	Interface Softening Temperature (°C)	Interface Melting Temperature (°C)	Softening Voltage U_{iso}^a (mV)	Melting Voltage U_{iso}^a (mV)	CSA C57 Current (A)	Softening or Melting Contact Resistance (mΩ)	Current Burst Level (A)
2/0	Cu	190	1083	60.1	286	380	0.158	1806
4/0	Al	150	660	43.7	187	408	0.107	1749

a. Using a bulk temperature of 100°C from CSA C57.

b. From Table 6 and Table 8 from CSA C57.

Table III. Calculated current burst levels

HOW TO AVOID THE REAL COST OF NON-COMPLIANCE IN STATIC CONTROL

Newson Gale

The overall cost of non-compliance can stretch far beyond potential “savings” achieved by ignoring the risk of electrostatic ignitions or by using non-compliant static control methods. More often than not, static caused fires and explosions result in expensive production downtime, legal and insurance costs related to personnel injuries & fatalities and damage to company property.

In numerous cases, static-caused fires have led to the pollution of the local environment, resulting in the loss of public goodwill and the payment of heavy fines imposed by local government. Under ATEX, the European Union’s legislation which governs the safety of personnel working in hazardous atmospheres, everybody from suppliers to company directors are open to criminal prosecution if a court determines that adequate Best Practice procedures and equipment have not been used to protect workers.

Fortunately, there are three industry-produced Best Practice standards that provide the background to the nature of static electricity, the processes that are susceptible to electrostatic ignitions and the preventative measures that should be put in place to eliminate static electricity as a health and safety risk. The best practice standards are:

- NFPA 77(2007): Recommended Practice on Static Electricity, (National Fire Protection Association).
- Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents, (2003), (American Petroleum Institute).
- Cenelec CLC/TR:50404 (2003): Electrostatics - Code of practice for the avoidance of hazards due to static electricity (Cenelec committee CLC/TC 31)

The standards are produced by committees made up of industry experts in hazardous process safety and show remarkable consistency in the precautionary measures identified for controlling the generation of static electricity.

For example, in tank truck transfers both CLC/TR: 50404 and API standards (NFPA references API for tank truck transfers) recommend:

1. the use of interlocks to stop flow of product preventing the generation of static if the truck loses its ground connection.
2. monitoring the bonding/grounding circuit to less than 10 ohms and providing positive indication to operators that a positive bond/ground connection is established.
3. state the first operation in road tanker transfers is to apply a full ground connection to the vehicle.

The API standard goes a step further stating the grounding clamp should not be removed until the tank truck body is sealed, i.e. removal of the grounding clamp should be the final operation in the product transfer process.

As recommended in each of the standards the most effective method of eliminating spark gaps is to ensure all conductive and semi-conductive objects are bonded and grounded with fit

for purpose static control equipment. The static control equipment should be capable of making low electrical resistance contact with charged equipment, combined with maintaining secure and reliable low resistance static dissipative circuits.

A good margin of safety can be achieved by ensuring that static dissipative circuits and their connections are regularly checked for resistances greater than 10 ohms. The NFPA 77 and API standards state electrical resistances higher than 10 ohms in metal circuits are indicative of a break in the continuity of the circuit, resulting in the potential and undesirable accumulation of static electricity.

The recommendation by all of the standards of monitoring up to 10 ohms is designed to compensate for the effect industrial environments can have on the capacity of equipment to dissipate static well before it has the potential to be a health and safety risk. Some examples include:

- inadequate mechanical penetration of electrostatically charged equipment.
- degradation of circuits and connections resulting from chemical, mechanical or environmental attack.
- infrequent or inadequate servicing of equipment.
- human errors in following the correct static control procedures.

The recommendation of utilizing <10 ohm circuits should not be confused with the resistance of 1×10^6 ohms often referred to throughout the standards. This is the generally accepted value of resistance capable of dissipating static. This theoretical value is based on the relatively small size of currents that generate static charges in relation to the very high voltages they are capable of inducing. In a basic $V = RI$ equation this makes sense, but when real world effects are taken into account, the standards recommend static dissipative circuits of 10 ohms or less.

To ensure complete protection from incendive spark discharges in operations that require frequent processing of hazardous materials, the standards recommend continuous monitoring of bonding/grounding circuits to 10 ohms or less.

This ensures that a proper bond or ground connection is established, preferably before the process is initiated, guaranteeing that an incendive spark will not be discharged throughout the process.

Another area that can be confusing when specifying fit for purpose static control equipment is identifying the difference between hazardous area electrical protection approvals (FM, UL, CSA, ATEX) and equipment designed to control electrostatic ignitions. Approval classifications should not be confused with specifying systems that demonstrate Best Practice compliance in the area of static control. Hazardous area certification only provides a method of protection that guarantees electrical faults are prevented from igniting flammable atmospheres. This has nothing to do with preventing the occurrence of incendive

spark discharges from industrial processes. In the same way gas analysers perform functions that detect gases before they become a health and safety risk, static control products should perform functions that ensure spark discharges are prevented well before they can become a hazard.

When specifying static control equipment, hazardous area operators should seek out equipment suppliers that can provide static control products that reinforce compliance with the various Best Practice standards for static control. Hazardous area operators can record this information in their Safety Report for review by the local Health and Safety inspector or corporate body responsible for occupational safety. Should there be an unfortunate incident, investigators will be in a position to rule out static electricity as an ignition source.

The standards for controlling static electricity as an ignition source in hazardous areas are available for purchase on each of the association's websites:

www.nfpa.org

www.cenelec.eu

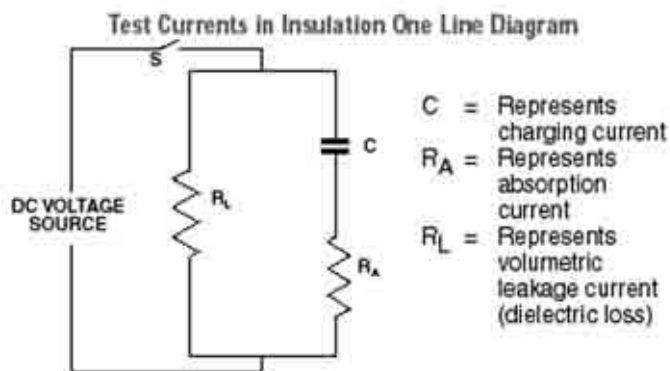
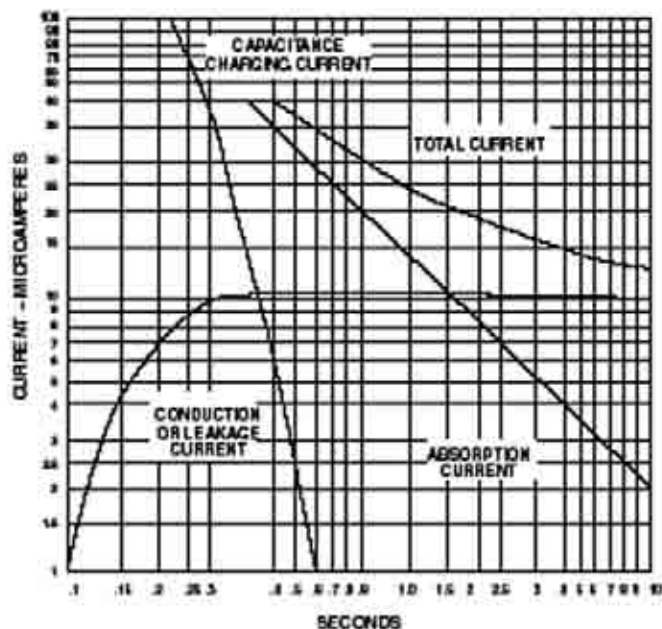
www.api.org

UNDERSTANDING INSULATION RESISTANCE TESTING

AEMC Instruments

WHY HAVE AN INSULATION TESTING PROGRAM?

A regular program of testing insulation resistance is strongly recommended to prevent electrical shocks, assure safety of personnel and to reduce or eliminate down time. It helps to detect deterioration of insulation in order to schedule repair work such as: vacuum cleaning, steam cleaning, drying and rewinding. It is also helpful when evaluating the quality of the repairs before the equipment is put back into operation.



WHAT CAUSES INSULATION FAILURE?

Some of the more common causes of insulation failure include: excessive heat or cold, moisture, dirt, corrosive vapors, oil, vibration, aging and nicked wiring. What tests are used to detect insulation deterioration? There are numerous maintenance tests for assessing insulation quality. The three tests discussed here are used primarily to test motor, generator and transformer insulation.

WHAT EQUIPMENT IS NECESSARY FOR CONDUCTING INSULATION RESISTANCE TESTS?

- Megohmmeter with a timed test function
- Temperature indicator
- Humidity meter (not necessary if equipment temperature is above the dew point)

TEST CURRENTS IN INSULATION

Total current in the body of the insulation is the sum of three components

- Capacitance Charging Current
- Absorption Current
- Leakage or Conduction Current

INSULATION RESISTANCE READINGS

Readings are time dependent

- at the start, capacitance is what you see first
- at or about one minute, absorption
- at 10 minutes, reading is mainly leakage current

These changing readings are best seen with analog bargraphs on digital instruments or needle movement on analog instruments.

SPOT READING TEST

METHOD

For this test, the megohmmeter is connected across the insulation of the windings of the machine being tested. A test voltage is applied for a fixed period of time, usually 60 seconds and a reading is taken. The spot reading test should only be carried out when the winding temperature is above the dew point. The operator should make a note of the winding temperature, so that it will be possible to correct the reading to a base temperature of 20°C.

TEST DURATION

To obtain comparable results, tests must be of the same duration. Usually the reading is taken after 60 seconds.

INTERPRETATION OF RESULTS

Proper interpretation of spot reading tests requires access to records of results from previous spot reading tests. For conclusive results, only use results from tests performed at the same test voltage for the same amount of time, and under similar temperature and humidity conditions. These readings are used to plot a curve of the history of insulation resistance. A curve showing a downward trend usually indicates a loss of insulation resistance due to unfavorable conditions such as: humidity, dust accumulation, etc. A very sharp drop indicates an insulation failure. See Figure 1.

Example of the variation of insulation resistance over a period of years:

At A, the effect of aging and dust accumulation is shown by decreasing values.

At B, the sharp drop indicates an insulation failure.

At C, the insulation resistance value after the motor has been rewound.

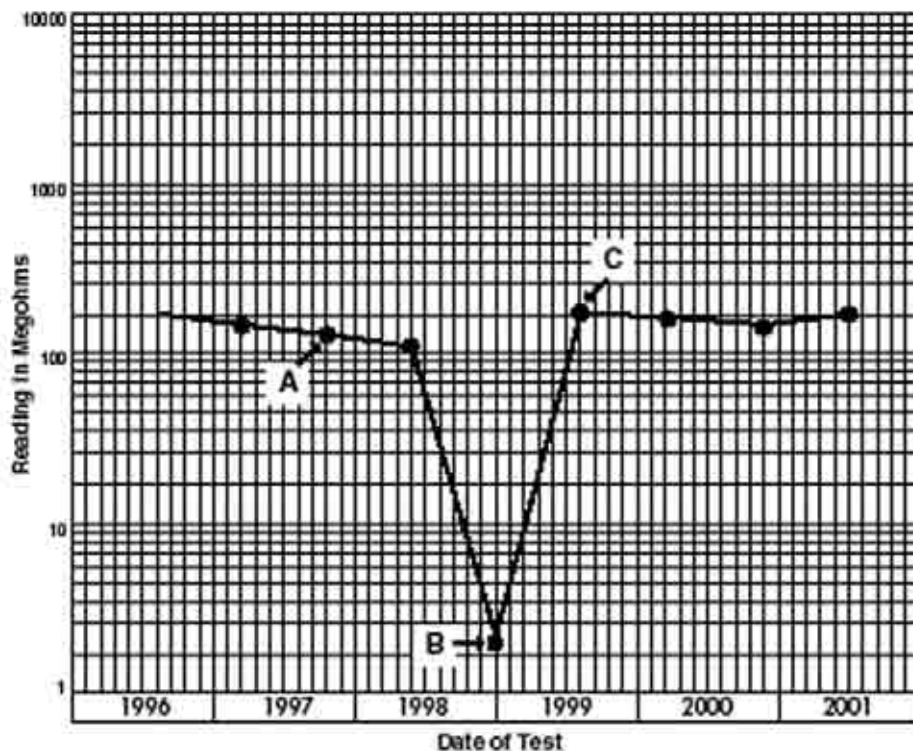


Figure 1

Dew point temperature is the temperature at which the moisture vapor in the air condenses as a liquid.

TIME-RESISTANCE TESTING METHOD

This method is fairly independent of temperature and often can give you conclusive information without records of past tests. It is based on the absorption effect of good insulation compared to that of moist or contaminated insulation. Simply take successive readings at specific times and note the differences in readings (see curves, Figure 2). Tests by this method are sometimes referred to as absorption tests.

Good insulation shows a continual increase in resistance (see curve D) over a period of time (in the order of 5 to 10 minutes). This is caused by the absorption; good insulation shows this charge effect over a time period much longer than the time required to charge the capacitance of the insulation.

If the insulation contains moisture or contaminants, the absorption effect is masked by a high leakage current which stays at a fairly constant value keeping the resistance reading low ($R = E/I$) (see curve E).

The time-resistance testing is of value because it is independent of equipment size. The increase in resistance for clean and dry insulation occurs in the same manner whether a motor is large or small. You can compare several motors and establish standards for new ones, regardless of their horsepower ratings.

Figure 2 shows how a 60-second test would appear for good and bad insulation. When the insulation is in good shape, the 60-second reading is higher than the 30-second reading.

A further advantage of this two reading test is that it gives you a clearer picture, even when a "spot reading" says the insulation looks ok.

Time-resistance tests on large rotating electrical machinery - especially with high operating voltage - require high insulation resistance ranges and a very constant test voltage. A heavy-duty megohmmeter serves this need. Similarly, such an instrument is better adapted for cables, bushings, transformers, and switchgear in the heavier-duty sizes.

Test Methods - Time-Resistant Tests Dielectric Absorption Ratio (DAR)

- The ratio of 60 seconds/30 seconds
- less than 1 = failed
- 1.0 to 1.25 = OK
- 1.4 to 1.6 = excellent
- Note: This is not a commonly used test

STEP VOLTAGE TEST

METHOD

In this test, the operator applies two or more test voltages in steps. The recommended ratio for the test voltage steps is 1 to 5. At each step, test voltage should be applied for the same length of time, usually 60 seconds. The application of increased voltage creates electrical stresses on internal insulation cracks. This can reveal aging and physical damage even in relatively dry and clean insu-

lation which would not have been apparent at lower voltages.

TEST DURATION

A series of "steps", each step lasting 60 seconds.

INTERPRETATION OF RESULTS

Compare the readings taken at different voltage levels, looking for any excessive reduction in insulation resistance values at the higher voltage levels. Insulation that is thoroughly dry, clean, and without physical damage should provide roughly the same resistance values despite changes in test voltage levels. If resistance values decrease substantially when tested at higher voltage levels, this should serve as a warning that insulation quality may be deteriorating due to dirt, moisture, cracking, aging, etc.

$$\text{Polarization Index (PI)} = \frac{\text{10-minute reading}}{\text{1-minute reading}}$$

The IEEE Std 43-2000 lists the following minimum values for the polarization index for AC and DC rotating machines:

Class A: 1.5 Class B: 2.0 Class C: 2.0

Absorption curve of test conducted on 350 HP Motor: Curve D indicates a good insulation with an excellent polarization index of 5. Curve E indicates a potential problem. The polarization index is only 140/95, or 1.47.

(2) IEEE Std. 43-2000, "Recommended Practice for Testing Insulation Resistance of Rotating Machinery." Available from the Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th St., New York, NY 10017.

BEFORE AND AFTER REPAIR:

Curve F shows a downward trend of insulation resistance values as the test voltage is increased. This indicates a potential problem with the insulation. Curve G shows the same equipment after it has been repaired.

UTILIZING THE GUARD TERMINAL

The guard terminal is useful when measuring very high resistance values.

WHAT TEST VOLTAGE SHOULD I USE?

There are two schools of thought regarding the voltage to test insulation at. The first applies to new equipment or cable and can use AC or DC test voltages.

When AC voltage is used, the rule of thumb is 2 x nameplate voltage + 1000. When DC voltage is used (most common on megohmmeters manufactured today) the rule of thumb is simply 2 x nameplate voltage except when higher voltages are used. See chart below for suggested values.

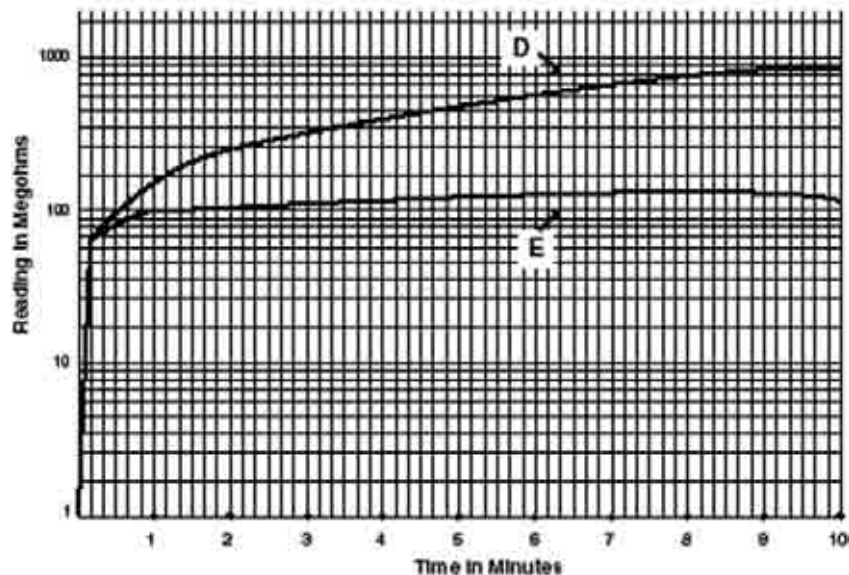
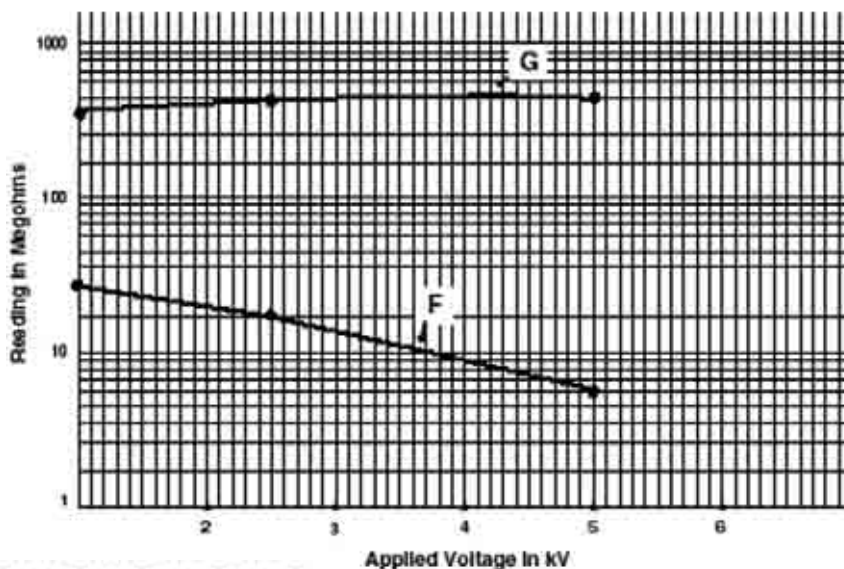


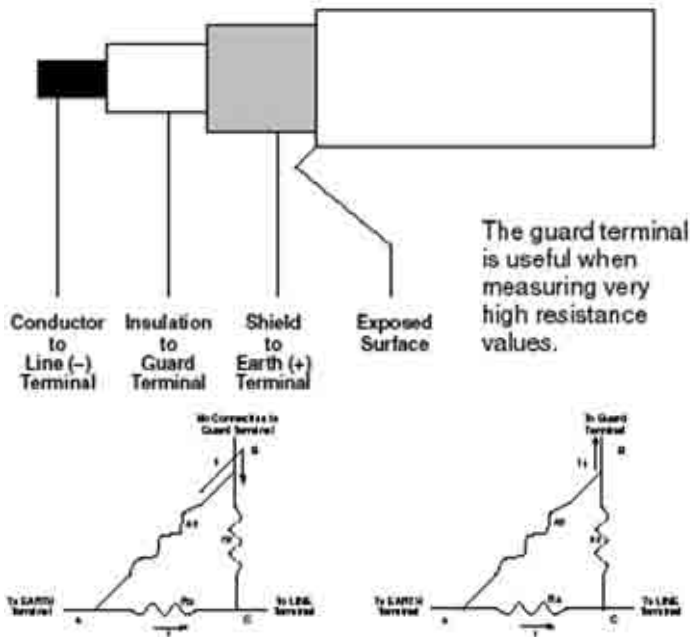
Figure 2

EQUIPMENT/CABLE RATING

24 to 50V
50 to 100V
100 to 240V
440 to 550V
2400V
4100V

DC Test Voltage
50 to 100VDC
100 to 250VDC
250 to 500VDC
500 to 1000VDC
1000 to 2500VDC
1000 to 5000VDC

It is always advisable to contact the original equipment manufacturer to get their recommendation for the proper voltage to use when testing their equipment.



corresponding wiring diagrams will completely test a three-phase transformer.

- High voltage winding to low voltage winding and ground
- High voltage winding to ground with low voltage winding to guard
- High voltage winding to low voltage winding
- Low voltage winding to ground and high voltage winding to guard
- High voltage winding to low voltage winding

⊕ = Earth Terminal ⊖ = Line Terminal G = Guard Terminal

CABLE TESTING

Transformers are tested at or above the rated voltage to be certain there are no excessive leakage paths to ground or between windings. These are conducted with the transformer completely disconnected from the line and load. However, the case ground should not be removed.

ADVANTAGES OF DC TESTING

- Lighter size and weight of test equipment
- Non-destructive
- Historical data can be compiled

TRANSFORMER TESTING

Transformers are tested at or above the rated voltage to be certain there are no excessive leakage paths to ground or between windings. These are conducted with the transformer completely disconnected from the line and load. However, the case ground should not be removed.

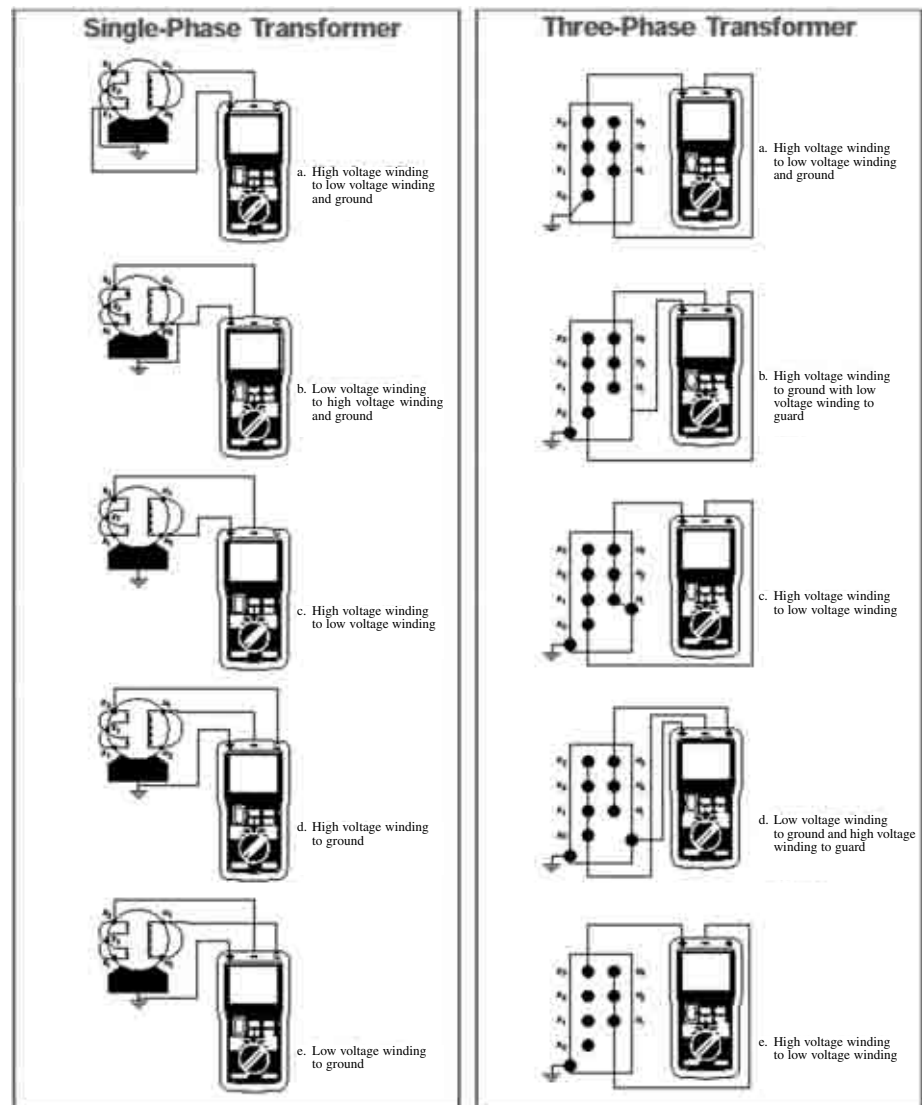
SINGLE-PHASE TRANSFORMER

The following 5 tests and corresponding wiring diagrams will completely test a single-phase transformer. Allow at least 1 minute for each test or until the reading stabilizes.

- High-voltage winding to low voltage winding and ground
- Low-voltage winding to high voltage winding and ground
- High-voltage winding to low voltage winding
- High-voltage winding to ground
- Low-voltage winding to ground

THREE-PHASE TRANSFORMER

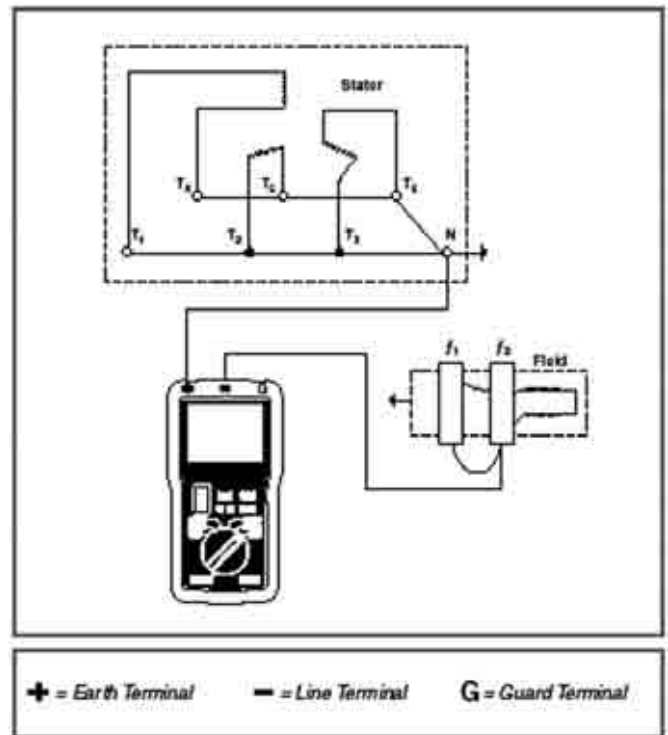
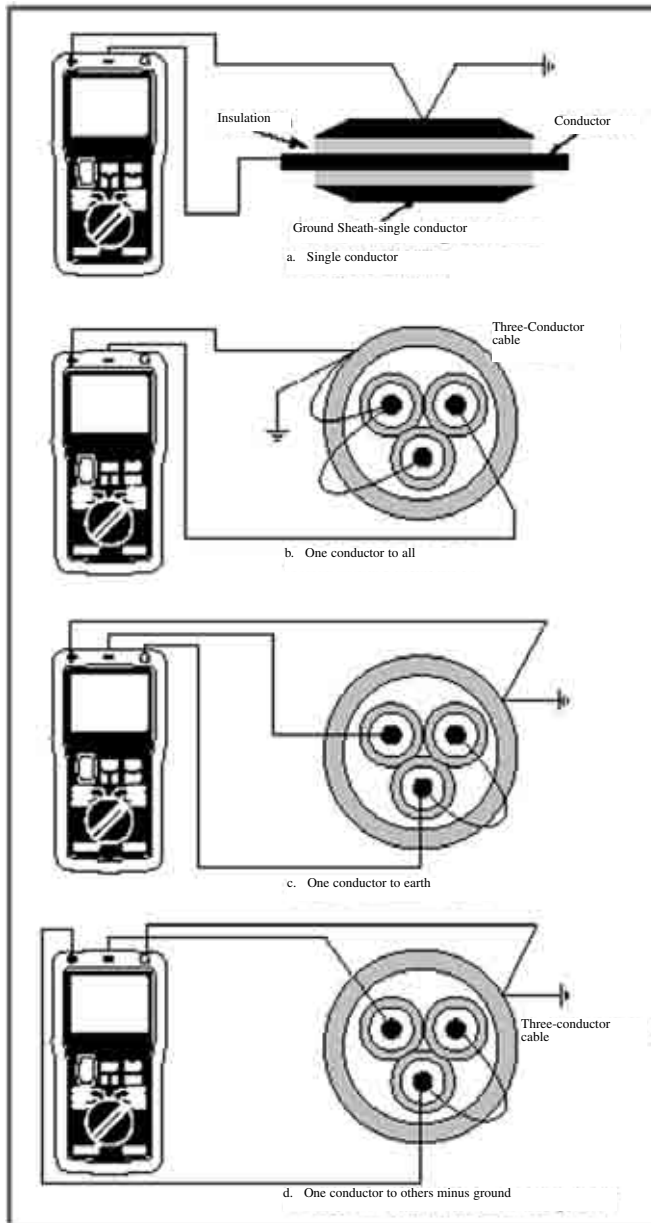
The following 5 tests and



SINGLE CONDUCTOR

Connect as shown in the diagram

- a. Conductor to Line (-) terminal and sheath to Earth (+)
 Multi-Conductor
 a. Single conductor
 b. One conductor to all
 c. One conductor to earth
 d. One conductor to others minus ground



MOTOR AND GENERATOR TESTING

Before testing the above, lift the rotor brushes, ground the starter terminal and frame and ground the motor shaft. Discharge the field winding by grounding, then remove the field winding from ground and connect to the (-) Line connection on the megohmmeter. Connect the (+) Earth terminal to ground. The diagram shows the connection for testing the field insulation resistance. The stator winding may also be measured in a similar manner.

10 DUMB THINGS SMART PEOPLE DO WHEN TESTING ELECTRICITY

Fluke Corporation

Anyone who makes his/her living by working with electricity quickly develops a healthy respect for anything with even a remote chance of being “live”.

Yet the pressures of getting a job done on time or getting a mission-critical piece of equipment back on line can result in carelessness and uncharacteristic mistakes by even the most seasoned electrician. The list below was developed as a quick reminder of what not to do when taking electrical measurements.

1. Replace the original fuse with a cheaper one.

If your digital multimeter meets today's safety standards, that fuse is a special safety sand fuse designed to pop before an overload hits your hand. When you change your DMM fuse, be sure to replace it with an authorized fuse.

2. Use a bit of wire or metal to get around the fuse all together.

That may seem like a quick fix if you're caught without an extra fuse, but that fuse could be all that ends up between you and a spike headed your way.

3. Use the wrong test tool for the job.

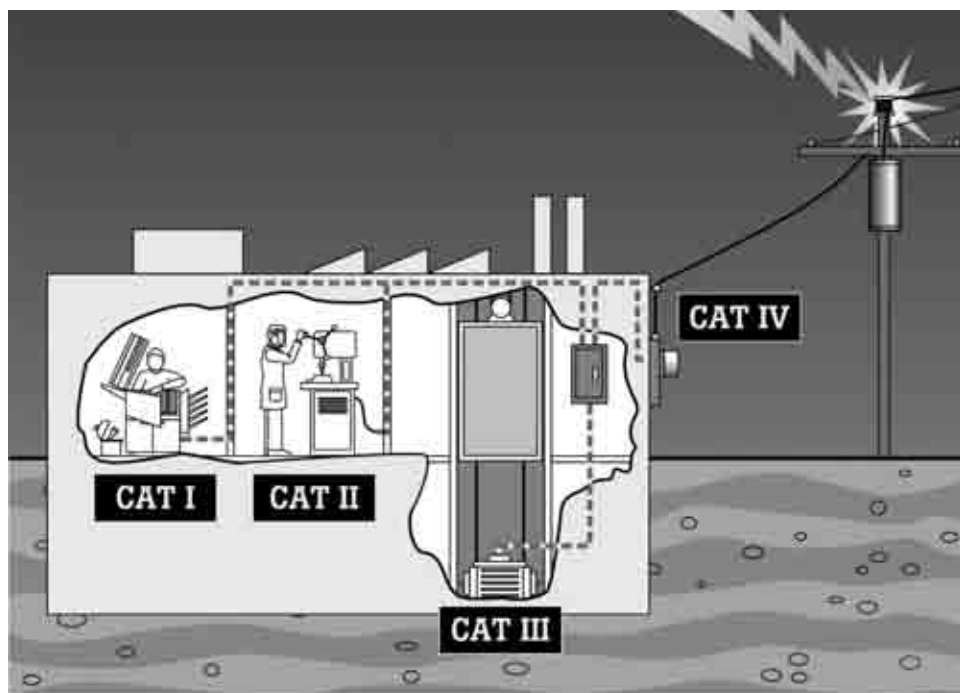
It's important to match your DMM to the work ahead. Make sure your test tool holds the correct CAT rating for each job you do, even if it means switching DMMs throughout the day.

4. Grab the cheapest DMM on the rack.

You can upgrade later, right? Maybe not, if you end up a victim of a safety accident because that cheap test tool didn't actually contain the safety features it advertised. Look for independent laboratory testing.

5. Leave your safety glasses in your shirt pocket.

Take them out. Put them on. It's important. Ditto insulated gloves and flame-resistant clothing.



Overvoltage category	In brief	Examples
CAT IV	Three-phase at utility connection, any outdoor conductors	- Refers to the "origin of installation"; i.e., where low-voltage connection is made to utility power. - Electricity meters, primary overcurrent protection equipment. - Outside and service entrance, service drop from pole to building, run between meter and panel. - Overhead line to detached building, underground line to well pump.
CAT III	Three-phase distribution, including single-phase commercial lighting	- Equipment in fixed installations, such as switchgear and polyphase motors. - Bus and feeder in industrial plants. - Feeders and short branch circuits, distribution panel devices. - Lighting systems in larger buildings. - Appliance outlets with short connections to service entrance.
CAT II	Single-phase receptacle connected loads	- Appliance, portable tools, and other household and similar loads. - Outlet and long branch circuits. - Outlets at more than 10 meters (30 feet) from CAT III source. - Outlets at more than 20 meters (60 feet) from CAT IV source.
CAT I	Electronic	- Protected electronic equipment. - Equipment connected to (source) circuits in which measures are taken to limit transient overvoltages to an appropriately low level. - Any high-voltage, low-energy source derived from a high-winding resistance transformer, such as the high-voltage section of a copier.

6. Work on a live circuit.

De-energize the circuit whenever possible. If the situation requires you to work on a live circuit, use properly insulated tools, wear safety glasses or a face shield and insulated gloves, remove watches or other jewelry, stand on an insulated mat and wear flame-resistant clothing, not regular work clothes.

7. Fail to use proper lockout/tag-out procedures.

8. Keep both hands on the test.

Don't! When working with live circuits, remember the old electrician's trick. Keep one hand in your pocket. That lessens the chance of a closed circuit across your chest and through your heart. Hang or rest the meter if possible. Try to avoid holding it with your hands to minimize personal exposure to the effects of transients.

9. Neglect your leads.

Test leads are an important component of DMM safety. Make sure your leads match the CAT level of your job as well. Look for test leads with double insulation, shrouded input connectors, finger guards and a non-slip surface.

10. Hang onto your old test tool forever.

Today's test tools contain safety features unheard of even a few years ago, features that are worth the cost of an equipment upgrade and a lot less expensive than an emergency room visit

ISOLATION TECHNOLOGIES FOR RELIABLE INDUSTRIAL MEASUREMENTS

National Instruments Corporation

OVERVIEW

Voltage, current, temperature, pressure, strain, and flow measurements are an integral part of industrial and process control applications. Often, these applications involve environments with hazardous voltages, transient signals, common-mode voltages, and fluctuating ground potentials capable of damaging measurement systems and ruining measurement accuracy. To overcome these challenges, measurement systems designed for industrial applications make use of electrical isolation. This white paper focuses on isolation for analog measurements, provides answers to common isolation questions, and includes information on different isolation implementation technologies.

UNDERSTANDING ISOLATION

Isolation electrically separates the sensor signals which can be exposed to hazardous voltages (Hazardous Voltages are greater than 30 Vrms, 42.4 Vpk or 60 VDC), from the measurement system's low-voltage backplane. Isolation offers many benefits including:

- Protection for expensive equipment, the user, and data from transient voltages
- Improved noise immunity
- Ground loop removal
- Increased common-mode voltage rejection

Isolated measurement systems provide separate ground planes for the analog front end and the system backplane to separate the sensor measurements from the rest of the system. The ground connection of the isolated front end is a floating pin that can operate at a different potential than the earth ground. Figure 1 represents an analog voltage measurement device. Any common-mode voltage that exists between the sensor ground and the measurement system ground is rejected. This prevents ground loops from forming and removes any noise on the sensor lines.

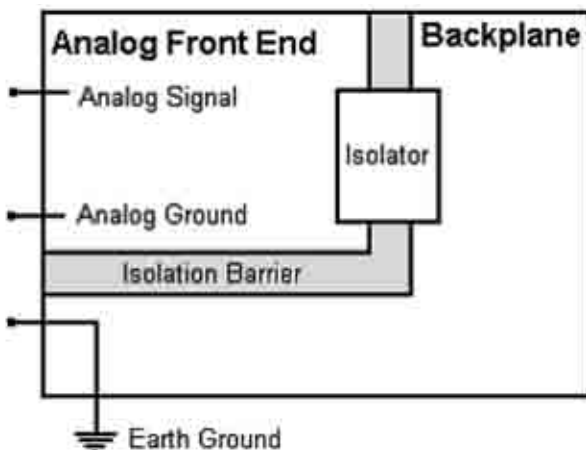


Figure 1. Bank Isolated Analog Input Circuitry

NEED FOR ISOLATION

Consider isolation for measurement systems that involve any of the following:

- Vicinity to hazardous voltages
- Industrial environments with possibility of transient voltages
- Environments with common mode voltage or fluctuating ground potentials
- Electrically noisy environments such as those with industrial motors
- Transient sensitive applications where it is imperative to prevent voltage spikes from being transmitted through the measurement system

Industrial measurement, process control, and automotive test are examples of applications where common-mode voltages, high voltage transients, and electrical noise are common. Measurement equipment with isolation can offer reliable measurements in these harsh environments. For medical equipment in direct contact with patients, isolation is useful in preventing power line transients from being transmitted through the equipment.

Based on your voltage and data rate requirements, you have several options for making isolated measurements. You can use plug-in boards for laptops, desktop PCs, industrial PCs, PXI, Panel PCs, and CompactPCI with the option of built-in isolation or external signal conditioning. Isolated measurements can also be made using programmable automation controllers (PACs) and measurement systems for USB.

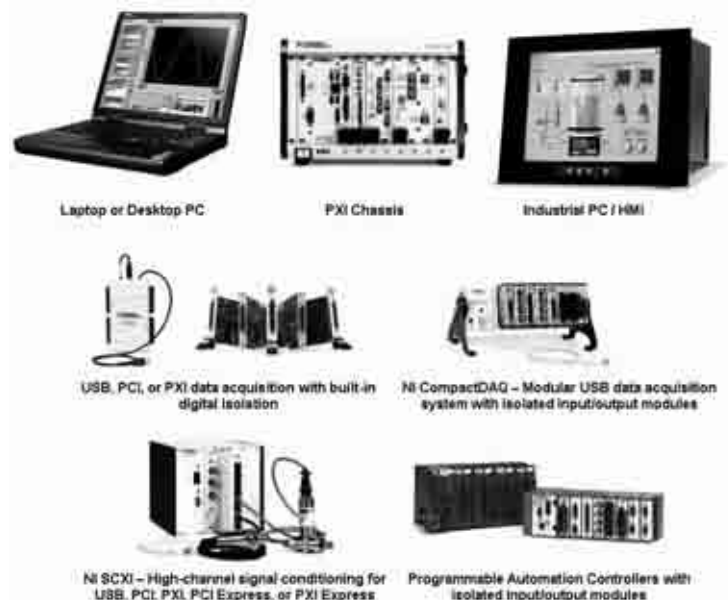


Figure 2. Isolated Data Acquisition Systems

METHODS OF IMPLEMENTING ISOLATION

Isolation requires signals to be transmitted across an isolation barrier without any direct electrical contact. Light emitting diodes (LEDs), capacitors, and inductors are three commonly available components that allow electrical signal transmission without any direct contact. The principles on which these devices are based form the core of the three most common technologies for isolation – optical, capacitive, and inductive coupling.

OPTICAL COUPLING

LEDs produce light when a voltage is applied across them. Optical isolation uses an LED along with a photo-detector device to transmit signals across an isolation barrier using light as the method of data translation. A photo-detector receives the light transmitted by the LED and converts it back to the original signal.

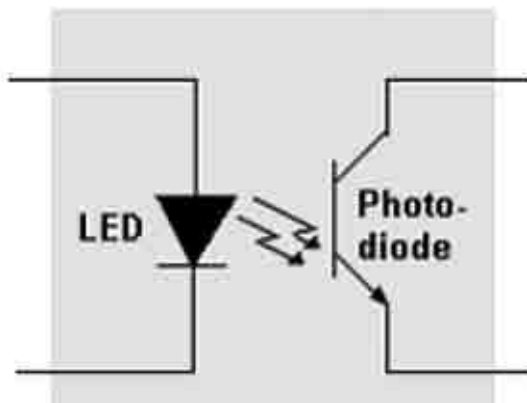


Figure 3. Optical Coupling

Optical isolation is one of the most commonly used methods for isolation. One benefit of using optical isolation is its immunity to electrical and magnetic noise. Some of the disadvantages include transmission speed, which is restricted by the LED switching speed, high-power dissipation, and LED wear.

CAPACITIVE COUPLING

Capacitive isolation is based on an electric field that changes based on the level of charge on a capacitor plate. This charge is detected across an isolation barrier and is proportional to the level of the measured signal.

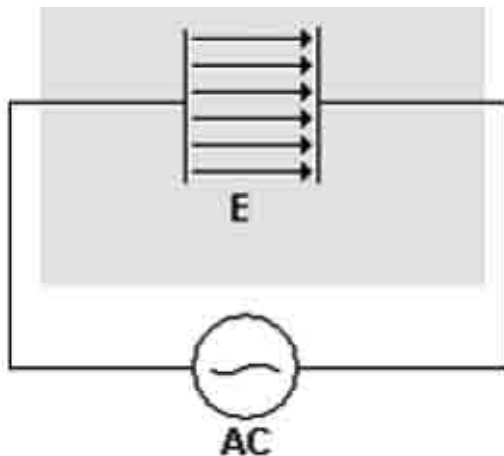


Figure 4. Capacitive Isolation

One advantage of capacitive isolation is its immunity to magnetic noise. Compared to optical isolation, capacitive isolation can support faster data transmission rates because there are no LEDs that need to be switched. Since capacitive coupling involves the use of electric fields for data transmission, it can be susceptible to interference from external electric fields.

INDUCTIVE COUPLING

In the early 1800s, Hans Oersted, a Danish physicist, discovered that current through a coil of wire produces a magnetic field. It was later discovered that current can be induced in a second coil by placing it in close vicinity of the changing magnetic field from the first coil. The voltage and current induced in the second coil depend on the rate of current change through the first. This principle is called mutual induction and forms the basis of inductive isolation.

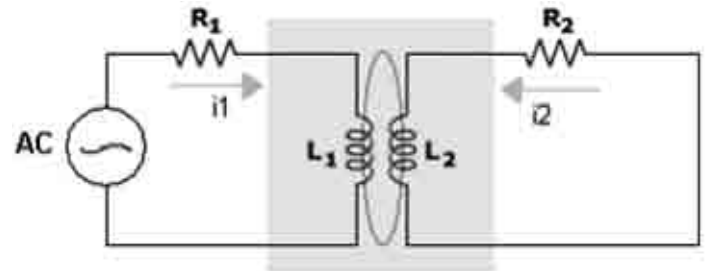


Figure 5. Inductive Coupling

Inductive isolation uses a pair of coils separated by a layer of insulation. Insulation prevents any physical signal transmission. Signals can be transmitted by varying current flowing through one of the coils, which causes a similar current to be induced in the second coil across the insulation barrier. Inductive isolation can provide high-speed transmission similar to capacitive techniques. Because inductive coupling involves the use of magnetic fields for data transmission, it can be susceptible to interference from external magnetic fields.

ANALOG ISOLATION AND DIGITAL ISOLATION

Several commercial off-the-shelf (COTS) components are available today, many of which incorporate one of the above technologies to provide isolation. For analog input/output channels, isolation can be implemented either in the analog section of the board, before the analog-to-digital converter (ADC) has digitized the signal (analog isolation) or after the ADC has digitized the signal (digital isolation). Different circuitry needs to be designed around one of these techniques based on the location in the circuit where isolation is being implementing. You can choose analog or digital isolation based on your data acquisition system performance, cost, and physical requirements. Figure 6 shows the different stages of implementing isolation.

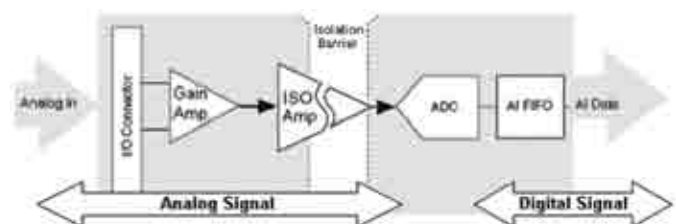


Figure 6a. Analog Isolation

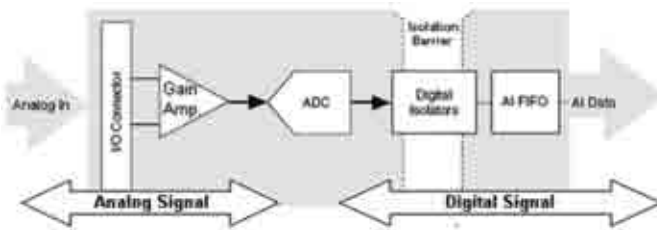


Figure 6b. Digital Isolation

The following sections cover analog and digital isolation in more detail and explore the different techniques for implementing each.

ANALOG ISOLATION

The isolation amplifier is generally used to provide isolation in the analog front end of data acquisition devices. “ISO Amp” in Figure 6a represents an isolation amplifier. The isolation amplifier in most circuits is one of the first components of the analog circuitry. The analog signal from a sensor is passed to the isolation amplifier, which provides isolation and passes the signal to the analog-to-digital conversion circuitry. Figure 7 represents the general layout of an isolation amplifier.

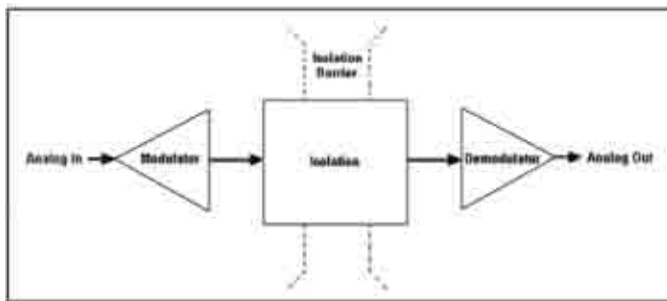


Figure 7. Isolation Amplifier

In an ideal isolation amplifier, the analog output signal is the same as the analog input signal. The section labeled “isolation” in Figure 7 uses one of the techniques discussed in the previous section (optical, capacitive, or inductive coupling) to pass the signal across the isolation barrier. The modulator circuit prepares the signal for the isolation circuitry. For optical methods, this signal needs to be digitized or translated into varying light intensities. For capacitive and inductive methods, the signal is translated into varying electric or magnetic fields. The demodulator circuit then reads the isolation circuit output and converts it back into the original analog signal.

Because analog isolation is performed before the signal is digitized, it is the best method to apply when designing external signal conditioning for use with existing non-isolated data acquisition devices. In this case, the data acquisition device performs the analog-to-digital conversion and the external circuitry provides isolation. With the data acquisition device and external signal conditioning combination, measurement system vendors can develop general-purpose data acquisition devices and sensor-specific signal conditioning. Figure 8 shows analog isolation being implemented with flexible signal conditioning that uses isolation amplifiers. Another benefit to isolation in the analog front end is protection for the ADC and other analog circuitry from voltage spikes.

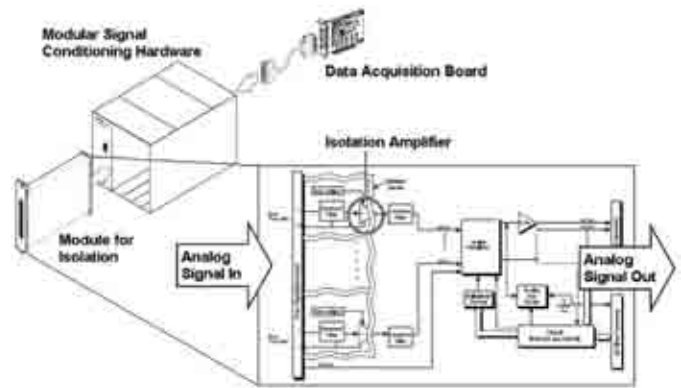


Figure 8. Use of Isolation Amplifiers in Flexible Signal Conditioning Hardware

There are several options available on the market for measurement products that use a general-purpose data acquisition device and external signal conditioning. For example, the National Instruments M Series includes several non-isolated, general-purpose multifunction data acquisition devices that provide high-performance analog I/O and digital I/O. For applications that need isolation, you can use the NI M Series devices with external signal conditioning, such as the National Instruments SCXI or SCC modules. These signal conditioning platforms deliver the isolation and specialized signal conditioning needed for direct connection to industrial sensors such as load cells, strain gages, pH sensors, and others.

DIGITAL ISOLATION

Analog-to-digital converters are one of the key components of any analog input data acquisition device. For best performance, the input signal to the analog-to-digital converter should be as close to the original analog signal as possible. Analog isolation can add errors such as gain, non-linearity and offset before the signal reaches the ADC.

Placing the ADC closer to the signal source can lead to better performance. Analog isolation components are also costly and can suffer from long settling times. Despite better performance of digital isolation, one of the reasons for using analog isolation in the past was to provide protection for the expensive analog-to-digital converters. As ADC prices have significantly declined, measurement equipment vendors are choosing to trade ADC protection for better performance and lower cost offered by digital isolators (see Figure 9).

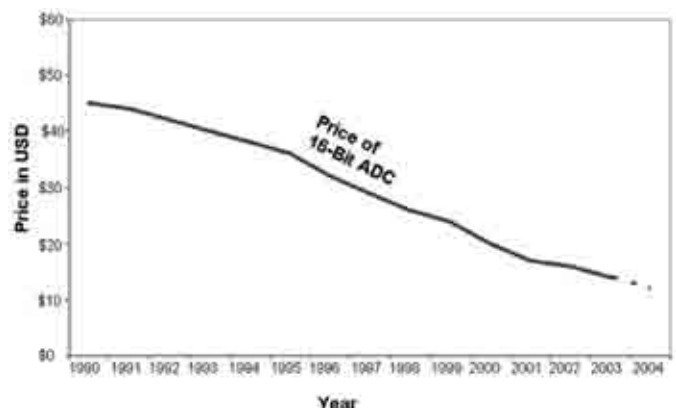


Figure 9. Declining Price of 16-Bit Analog-to-Digital Converters

Graph Source: National Instruments and a Leading ADC Supplier

Compared to isolation amplifiers, digital isolation components are lower in cost and offer higher data transfer speeds.

Digital isolation techniques also give analog designers more flexibility to choose components and develop optimal analog front ends for measurement devices. Products with digital isolation use current- and voltage-limiting circuits to provide ADC protection. Digital isolation components follow the same fundamental principles of optical, capacitive, and inductive coupling that form the basis of analog isolation.

Leading digital isolation component vendors such as Avago Technologies, Texas Instruments and Analog Devices have developed their isolation technologies around one of these basic principles. Avago Technologies offers digital isolators based on optical coupling, Texas Instruments bases its isolators on capacitive coupling, and Analog Devices isolators use inductive coupling.

OPTOCOUPLEDERS

Optocouplers, digital isolators based on the optical coupling principles, are one of the oldest and most commonly used methods for digital isolation. They can withstand high voltages and offer high immunity to electrical and magnetic noise. Optocouplers are often used on industrial digital I/O products, such as the National Instruments PXI-6514 isolated digital input/output board (see Figure 10) and National Instruments PCI-7390 industrial motion controller.

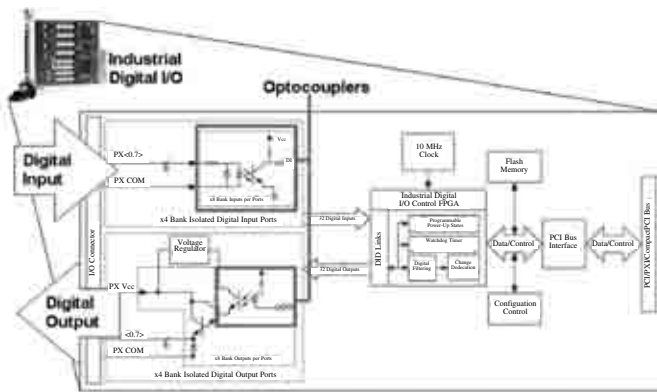


Figure 10. Industrial Digital I/O Products Use Optocouplers

For high-speed analog measurements, optocouplers, however, suffer from speed, power dissipation, and LED wear limitations associated with optical coupling. Digital isolators based on capacitive and inductive coupling can alleviate many optocoupler limitations.

CAPACITIVE ISOLATION

Texas Instruments offers digital isolation components based on capacitive coupling. These isolators provide high data transfer rates and high transient immunity. Compared to capacitive and optical isolation methods inductive isolation offers lower power consumption.

INDUCTIVE ISOLATION

iCoupler technology, introduced by Analog Devices in 2001, uses inductive coupling to offer digital isolation for high-speed and high-channel-count applications. iCouplers can provide 100 Mb/s data transfer rates with 2,500 V isolation withstand; for a 16-bit analog measurement system that implies sam-

pling rates in the mega hertz range. Compared to optocouplers, iCouplers offer other benefits such as reduced power consumption, high operating temperature range up to 125°C, and high transient immunity up to 25 kV/ms.

iCoupler technology is based on small, chip-scale transformers. An iCoupler has three main parts – a transmitter, transformer, and a receiver. The transmitter circuit uses edge trigger encoding and converts rising and falling edges on the digital lines to 1 ns pulses. These pulses are transmitted across the isolation barrier using the transformer and decoded on the other side by the receiver circuitry (see Figure 11). The small size of the transformers, about three-tenths of a millimeter, makes them practically impervious to external magnetic noise. iCouplers can also lower measurement hardware cost by integrating up to four isolated channels per integrated circuit (IC) and, compared to optocouplers, they require fewer external components.

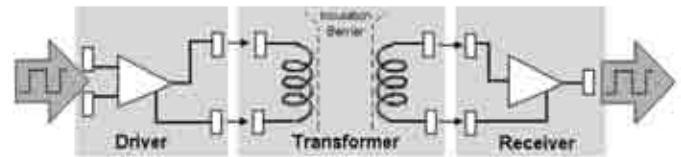


Figure 11. Induction Coupling-Based iCoupler Technology from Analog Devices

Source: Analog Devices

Measurement hardware vendors are using iCouplers to offer high-performance data acquisition systems at lower costs.

National Instruments industrial data acquisition devices intended for high-speed measurements, such as the isolated M Series multifunction data acquisition devices, use iCoupler digital isolators (see Figure 12). These devices provide 60 VDC continuous isolation and 1,400 Vrms/1,900 VDC channel-to-bus isolation withstand for 5 s on multiple analog and digital channels and support sampling rates up to 250 kS/s. National Instruments C Series modules used in the NI PAC platform, NI CompactRIO, NI CompactDAQ, and other high-speed NI USB devices also use the iCoupler technology.

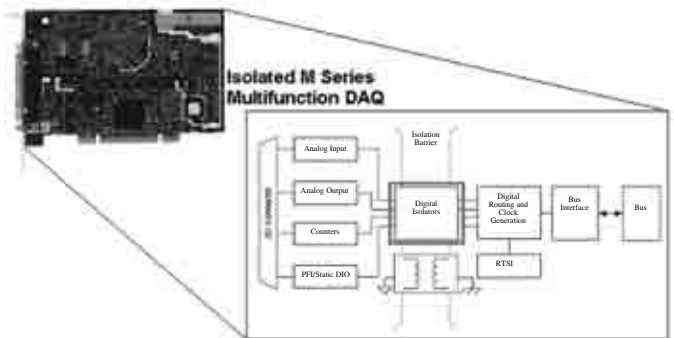


Figure 12. National Instruments Isolated M Series Multifunction DAQ Uses

SUMMARY

Isolated data acquisition systems can provide reliable measurements for harsh industrial environments with hazardous voltages and transients. Your need for isolation is based on your measurement application and surrounding environments. Applications that require connectivity to different specialty sensors using a single, general-purpose data acquisition device can

benefit from external signal conditioning with analog isolation, whereas applications needing lower-cost, high-performance analog inputs benefit from measurement systems with digital isolation technologies.

Isolated Products from National Instruments

	NI Isolated M Series and S Series • NI USB-6218 - Bank isolated USB multifunction DAQ • NI PCI-6230 - Bank isolated PCI/PXI multifunction DAQ • NI PCI-6154 - Ch-Ch isolated PCI simultaneous sampling DAQ
	NI CompactDAQ - USB Data Acquisition System • NI 9211 - Bank isolated thermocouple input module • NI 9206 - Bank isolated 600 VDC CAT I analog input module
	NI SCXI High-Channel External Signal Conditioning • NI SCXI-1125 - Ch-Ch isolation amplifier • NI SCXI-1121 - Bank isolated universal input sensor measurement amplifier
	NI CompactRIO - Reconfigurable Embedded Control and Acquisition System • NI 9203 - Isolated current input module • NI 9422 - Ch-ch isolated digital input module
	NI Compact FieldPoint - Distributed Programmable Automation Controller • NI cFP-TC-125 - Ch-Ch isolated thermocouple input module • NI cFP-AI-118 - Ch-Ch isolated voltage input module
	NI Motion Plug-in Motion Controller with Isolation NI Serial
	RS-232 and RS-485 Devices with Isolation

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INTER-SYSTEM GROUND NOISE: CAUSE AND EFFECTS

American Power Conversion

INTRODUCTION

A UPS system is an essential part of a business computer system, but it cannot completely protect the computer from all power related problems. In working with installers of business computer systems over time, APC has identified installation configurations which have special risks. Most computer power protection equipment is designed to protect the load or loads, which are attached. In the ideal case, no connection point to the computer exists except for the AC power cord. This allows the power protection equipment complete control over noise or transient voltage events that could enter the computer from the outside world.

In the real world, computers are more often than not interconnected to other remote devices via network wiring, printer data lines, and modem telephone lines. AC power protection equipment cannot stop transients from entering the computer via these data connections. In fact, these connections may allow a dangerous and common type of AC power problem to damage hardware or stored data. The problem is INTER-SYSTEM GROUND NOISE and it cannot be corrected using typical AC-only power protection equipment.

SAFETY GROUNDING

All computer equipment is equipped with three wire grounding type AC power connectors. Many types of equipment, such as lamps, have only two wire-type plugs since two wires are all that is necessary to deliver AC power. The third wire is a safety ground wire, which is connected to all exposed exterior metal parts on the computer equipment. The grounding connection provided at the wall receptacle is connected within the building to copper water pipes and/or structural metal parts of the building. The purpose of this arrangement is to protect the user from electrical shock when the exposed metal parts of a faulty computer and building structural metal parts are touched. For safety, exposed devices such as RS-232 connectors and printer ports are considered to be exposed metal parts. For this reason, the voltage at any connector pin must be ground, or present a small voltage with respect to ground. The result is that in virtually all computer equipment, the CPU common wire or ground reference is connected to the safety grounding wire (and the enclosure) of the equipment.

In a system including equipment that is interconnected via data lines, the safety grounding arrangement leads to a conflict. Every interconnected device has two connections which are attempting to establish the common reference voltage for data communications: 1) the common wire in the data line, which connects the device to other equipment, and 2) the device's safety grounding wire. This situation is sometimes known as a "ground loop". In the next section it will be shown how the existence of this loop can lead to differences between

the common reference voltage between any interconnected devices, which can be damaging to hardware and data. These ground voltage differences between interconnected devices must not be confused with other power problems such as common mode noise, normal mode noise, EMI, or RFI. These ground voltage differences are referred to as INTER-SYSTEM GROUND NOISE.

INTER-SYSTEM GROUND NOISE IS NOT THE SAME AS COMMON MODE NOISE

One of the most widespread misunderstandings in the field of computer power protection is the difference between inter-system ground noise and common mode noise. Common mode noise is defined as noise that exists between the power conductors, hot and neutral, with respect to the ground conductor. Inter-system ground noise exists between the ground wires supplying interconnected computers. Free standing computers which are not connected via any data lines cannot experience inter-system ground noise. It is possible for a computer to experience severe common mode noise, while experiencing no inter-system ground noise, and vice-versa. These two problems are completely independent.

A key reason why there is so much confusion in this area stems from the fact that power protection equipment can reduce common mode noise but cannot help correct inter-system ground noise. Power protection manufacturers, in fact, have an interest in leading users to believe that inter-system ground noise is equivalent to common mode noise because they make products that correct common mode noise. The literature and popular thinking on this subject mistakenly emphasize common mode noise while ignoring inter-system ground noise because sales and technical literature from power protection manufacturers are the leading sources of information on these subjects.

SOURCES AND EFFECTS OF INTER-SYSTEM GROUND NOISE

A simplified diagram of an ideal interconnected system is shown in Figure 1. The grounding wires from all of the interconnected equipment come from the same source, ensuring that they start out having the same voltage. No current of any kind flows in any of the ground wires, and they are not subject to any magnetic fields. This ensures that there can be no voltage drop along the ground wires. The result is that all points along all of the ground wires are at the same voltage and that there is no inter-system ground noise between devices attached at various points along the grounding system. The oscillographs in the figure show no current noise.

Unfortunately, significant effects prevent realization of the preceding ideal scenario. In some cases, the deviation from the ideal can result in data corruption and even hardware damage. An interconnected system experiencing inter-system

ground noise is shown in Figure 2. In the figure, interconnected systems are subject to different ground noise voltages, giving rise to ground noise current in the data line which connects the two systems. The offending ground noise in this case results from noise current injected into the ground system of one of the computers by "other equipment". Inter-system ground noise can result from a variety of different problems, which are explained as follows:

GROUND NOISE INJECTION: Although the safety ground wire is intended for grounding of the equipment enclosure, all computer equipment uses this wire for another purpose - to provide a reference point to filter out unwanted emissions of radio frequency interference from the computer equipment. Common and normal mode electrical noise on the power line is

injected into the ground line by the filter present in the power supply of each computer and workstation. Improperly designed surge suppressors may contribute to this problem.

EFFECT: This injected noise current gives rise to a noise voltage between the common references of the interconnected equipment. Because the noise voltages usually become larger when the distance between the equipment is increased, data transmissions can become compromised in some situations.

GROUND FAULTS: If the interconnected devices are on different electrical circuits in the building and one of these circuits is shared by some other unrelated equipment, which has an insulation failure, then before the circuit breaker trips, a very large fault current will be injected into the safety ground wire.

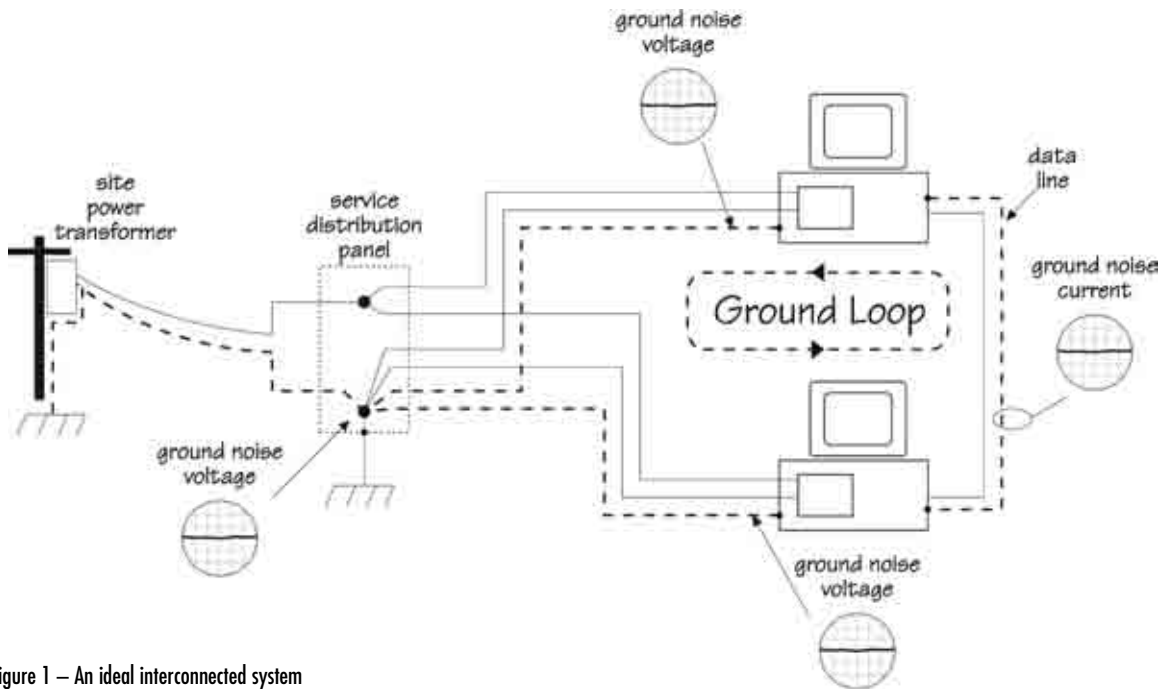


Figure 1 – An ideal interconnected system

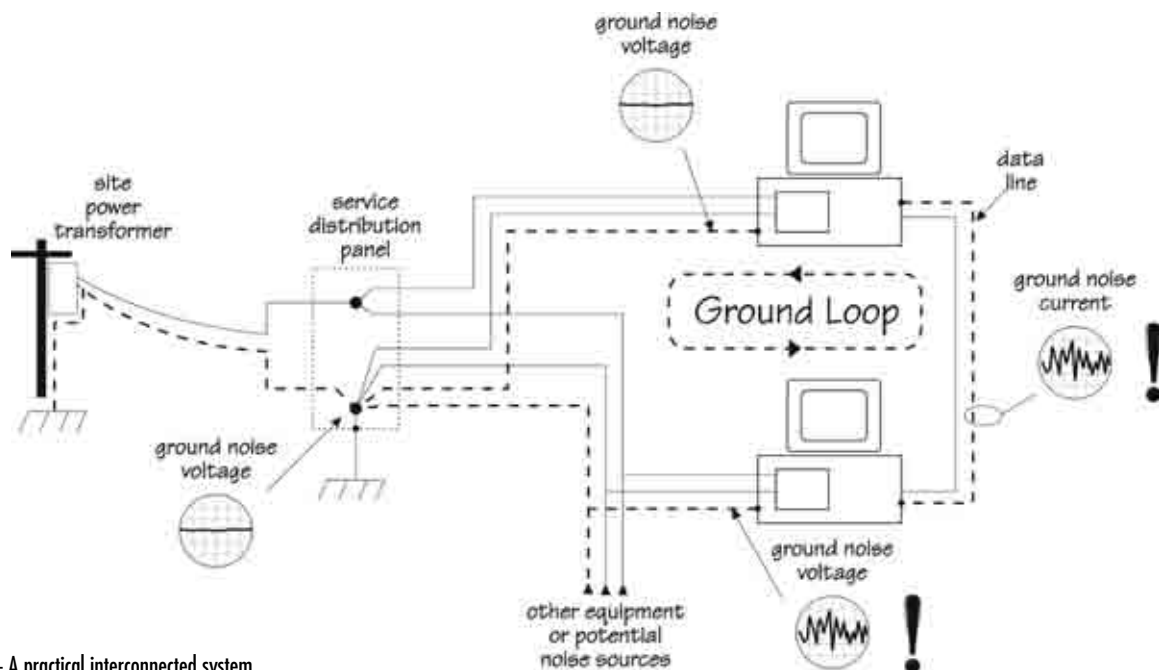


Figure 2 – A practical interconnected system

This will give rise to a momentary ground voltage surge at the computer equipment that is supplied by the circuit breaker, which is tripping. The size of this voltage surge may be from a few Volts to over one-half of the rated power voltage (either 120VAC or 230VAC), depending on the quality of the grounding system.

EFFECT: This will result in a voltage difference between the common reference points of the interconnected equipment that can easily exceed the data signal safety voltage rating. Destruction of input/output drivers and CPU motherboards can result.

GROUND CURRENTS: This is the most common problem identified. If the pieces of interconnected equipment are supplied by different electrical sub-panels (circuit breaker boxes) in the same or different buildings, then many problems can cause the ground voltage supplied to the interconnected devices to be different. Depending on local or national electrical codes, many different wiring systems are possible between separate sub-panels. Most of these inter-panel wiring systems do not guarantee that the ground voltages supplied by the sub-panels will be equal. In many cases the inter-panel ground connections are themselves part of other ground loops (such as building frame members) unrelated to the ground loops caused by the device data connection. A large number of situations can give rise to dangerous ground voltage differences between sub-panels including nearby lightning strikes to ground, lightning induced currents in ground loops external to the ground loop caused by device data connections, poor building grounding (sandy soil), fault currents (breaker tripping) in apparently unrelated buildings or circuits, or nearby electrical repair work.

EFFECT: This will result in a voltage difference between the common reference points between devices, which can easily exceed the data cable safety voltage rating. Destruction of data interface drivers and CPU motherboards can result. Another common side effect is heating of the data cabling (cable becomes warm or hot to the touch).

LIGHTNING INDUCED VOLTAGES: This is a common and damaging form of ground voltage noise. In this case, the ground loop acts as an antenna. Nearby lightning strikes create enormous electromagnetic pulse noise, which is received by the antenna. A large circulating current in the ground loop can be created.

EFFECT: This current may cause the voltage difference between the common reference points on interconnected devices to exceed the safety voltage rating. Damage to the data interface driver cards is common, and propagation of the damage into the CPU motherboard is possible. The area of the ground loop controls the magnitude of the problem. In rare circumstances, other types of equipment may create electromagnetic pulses, which are picked up by the ground loop (such as NMR/MRI imaging machines).

BREAKING GROUND LOOPS BY CUTTING WIRES

It may be apparent that the source of all of these problems is the ground loop caused by the electrical safety ground. In many cases, disconnection of this ground at one piece of equipment may prevent problems.

However, ground wire disconnection should never be performed because it is illegal and presents a severe shock hazard. It is sometimes suggested that an isolation transformer might be used to solve the ground loop problem. This will not work because all safety agencies require that the ground wire of

an isolation transformer be passed through between the input and output (only the power wiring may be isolated).

SOME EQUIPMENT IS RELATIVELY IMMUNE TO INTER-SYSTEM GROUND NOISE

Some network wiring is completely isolated and does not create ground loops when used to interconnect equipment. In this case, inter-system ground noise voltages can exist, but will have no effect. Examples of such immune network wiring are Ethernet and fiber-optic cables.

SOME EQUIPMENT IS VERY VULNERABLE TO INTER-SYSTEM GROUND NOISE

Examples of interconnections which are subject to inter-system ground noise are RS-232 data links, long printer data wiring, USB wiring, and network AUI wiring.

CONCLUSION

Inter-System Ground Noise is a type of power problem that is not widely understood but can result in misoperation or even destruction of equipment. The widespread use of Ethernet and optic fiber network connections, which are electrically isolated, has decreased the problem over time. However, non-isolated equipment connections such as RS-232, parallel, and USB can give rise to situations where Inter-System Ground noise poses a risk to equipment operation. Such connections should be kept short and the interconnected equipment should be powered from the same branch circuit.

AC MOTOR SELECTION AND APPLICATION GUIDE

GE Industrial Systems

VOLTAGE

DEFINITION

The motor nameplate voltage is determined by the available power supply which must be known in order to properly select a motor for a given application. The nameplate voltage will normally be less than the nominal distribution system voltage.

The distribution voltage is the same as the supply transformer voltage rating; the utilization (motor nameplate) voltage is set at a slightly lower level to allow for a voltage drop in the system between the transformer and the motor leads.

Some specifications still call for 220, 440 or 550 volt motors which were the long accepted standards. However, modern distribution systems have transformers located adjacent to secondary unit substations or load centers, plant wide power factor correction and shorter power line runs. The result is a stiffer distribution system which delivers higher voltage at the motor. The following motor nameplate voltages provide the best match to distribution system voltages and meet current motor design practices.

Table 1. Standard 60 hertz Nameplate Voltages

Nominal Distribution System Voltage	Motor Nameplate Voltage	
	Below 125 Hp	125 Hp and Up
Polyphase 60 hertz		
208	200	—
240	230	—
480	460	460
600	575	575
2400	2300	2300
4160	4000	4000
Single-phase 60 hertz		
120	115	—
208	200	—
240	230	—

Table 2. Standard 50 hertz Nameplate Voltages

Nominal Distribution System Voltage	Motor Nameplate Voltage	
	Below 125 Hp	125 Hp and Up
Polyphase 50 hertz		
See Note	200	—
	220	—
	380	380
	415	415
	440	440
	550	550
	3000	3000
Single-phase 50 hertz		
See Note	110	—
	200	—
	220	—

NOTE: Distribution system voltages vary from country to country; therefore, motor nameplate voltage should be selected for the country in which it will be operated.

SPECIAL VOLTAGES

Special motor designs are required for nameplate voltages other than those listed in Tables 1 and 2. Motors greater than 100 horsepower rated less than 345 volts will not be furnished without approval of the Company. Motors with nameplate voltages different than those listed in Tables 1 or 2 should be referred to the Company.

DUAL VOLTAGE MOTORS

Polyphase and single-phase motors may be furnished as dual voltage ratings under the following conditions:

1. Both voltages are standard for the particular rating as listed in Tables 1 and 2.
2. The two voltages are in a ratio of either 1:2 or 1: $\sqrt{3}$ (e.g. 230/460, 60 Hz; 2300/4000, 60 Hz; or 220/380, 50 Hz).
3. Single-phase voltage ratios are 1:2 only.

VOLTAGE AND FREQUENCY VARIATION

All motors are designed to operate successfully with limited voltage and frequency variations. However, voltage variation with rated frequency must be limited to $\pm 10\%$ and frequency variations with rated voltage must be limited to $\pm 5\%$. The combined variation of voltage and frequency must be limited to the arithmetic sum of 10%. Variations are expressed as deviation from motor nameplate values, not necessarily system nominal values. The allowable $\pm 10\%$ voltage variation is based upon the assumption that horsepower will not exceed nameplate rating and that motor temperature may increase. For instance, a 230 volt motor operating at 207 volts (90% of rated) loses any service factor indicated on the nameplate, and could run hotter than at rated voltage.

The following conditions are likely to occur with variations in voltage:

A. An increase or decrease in voltage may result in increased heating at rated horsepower load. Under extended operation this may accelerate insulation deterioration and shorten motor insulation life.

B. An increase in voltage will usually result in a noticeable decrease in power factor. Conversely, a decrease in voltage will result in an increase in power factor.

C. Locked-rotor and breakdown torque will be proportional to the square of the voltage. Therefore, a decrease in voltage will result in a decrease in available torque.

D. An increase of 10% in voltage will result in a reduction of slip of approximately 17%. A voltage reduction of 10% would increase slip by about 21%.

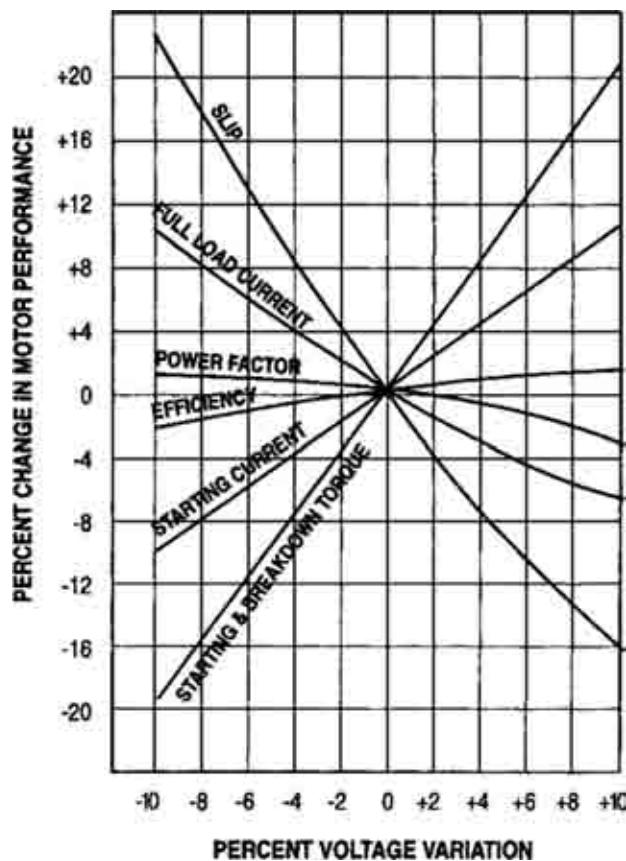


Figure 1. Voltage Variation

The following conditions are likely to occur with variations in frequency:

A. Frequency greater than rated frequency normally improves power factor but decreases locked-rotor and maximum torque. This condition also increases speed, and therefore, friction and windage losses.

B. Conversely, a decrease in frequency will usually lower power factor and speed while increasing locked-rotor maximum torque and locked-rotor current.

VOLTAGE UNBALANCE

Unbalanced line voltages applied to a polyphase motor result in unbalanced currents in the stator windings. Even a small percentage of voltage unbalance will result in a larger percentage of current unbalance, thus increasing temperature rise and possibly resulting in nuisance tripping.

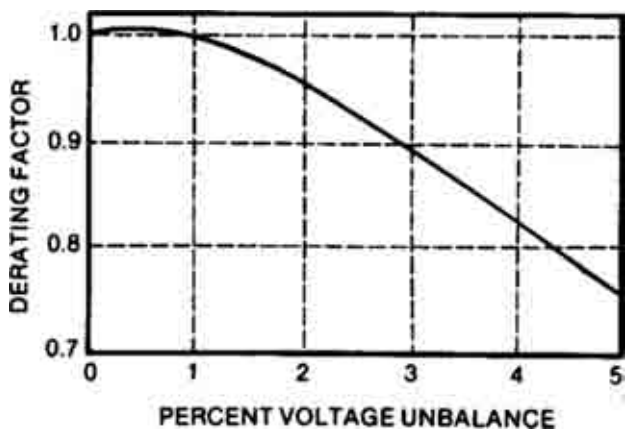


Figure 3. Voltage Unbalance

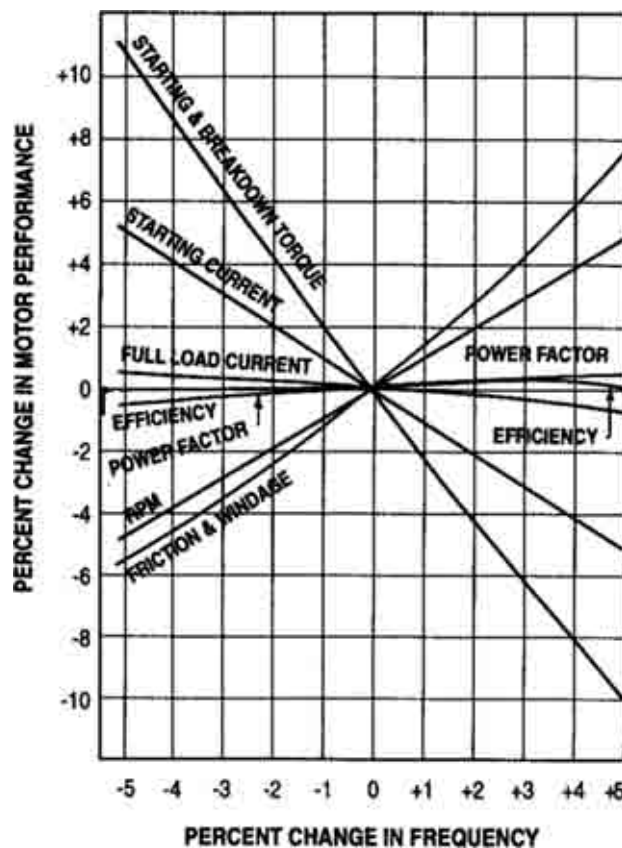


Figure 2. Frequency Variation

Voltages should be as evenly balanced as can be read on a voltmeter. If voltages are unbalanced, the rated horsepower of the motor should be derated, based upon the percent unbalance, as shown in the previous graph:

Percent voltage unbalance is calculated as follows:

$$\text{Percent Unbalance} = 100 \times \frac{\text{Maximum Voltage Deviation From Average Voltage}}{\text{Average Voltage}}$$

For instance, a 100 horsepower, three-phase motor operating with voltages of 598, 575 and 552 applied at the motor terminals is running with a 4% voltage unbalance ($100 \times 23/575$). Consequently, the rated output of 100 horsepower should be derated to approximately 82 Hp to reduce the possibility of damage to the motor. Motor operation above 5% voltage unbalance is not recommended.

Unbalanced voltages will produce the following effects on performance characteristics:

- Torques:** Unbalanced voltage results in reduced locked-rotor and breakdown torques for the application.
- Full-Load Speed:** Unbalanced voltage results in a slight reduction of full-load speed.
- Current:** Locked-rotor current will be unbalanced to the same degree that voltages are unbalanced but locked-rotor KVA will increase only slightly. Full-load current at unbalanced voltage will be unbalanced in the order

of six to ten times the voltage unbalance.

Temperature Rise: A 3.5% voltage unbalance will cause an approximate 25% increase in temperature rise.

LOW STARTING VOLTAGE

Large motors may experience a considerable voltage drop at the motor terminals when started due to large inrush current values.

Motors can be designed to compensate for this drop in voltage. For example, motors in frames 182-5013 can be supplied for operation under low starting voltage conditions down to 65% of nameplate rated voltage. The inertia referred to the motor shaft, the type of load (constant or variable torque), and the expected voltage drop must be provided to allow evaluation of the application for each rating involved.

In any case, motors designed for low starting voltage may have higher than standard inrush current when started on full rated voltage.

FREQUENCY

DEFINITION

Frequency can be defined as the number of complete alternations-per-second of an alternating current.

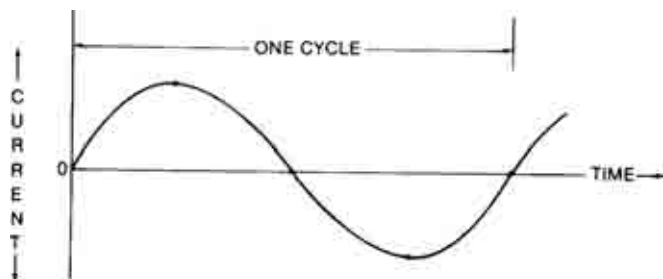


Figure 4.

As shown in Figure 4, current is said to have been through one complete cycle when it has gone from zero to maximum, to minimum, and back to zero again. Frequency is the number of these complete cycles over the passage of time and is usually expressed as hertz (Hz): one hertz equals one cycle per second (cps). Predominant frequency in North America is 60 Hz.

FREQUENCY STANDARDS

The predominant frequency in the United States is 60 hertz.

However, 50 hertz systems are common in other countries. Other systems, such as 40 and 25 hertz are isolated and relatively few in number.

50 HZ OPERATION OF 60 HZ MOTORS

General Electric standard motors rated at 60 Hz may be successfully operated at 50 Hz at reduced voltage and horsepower as shown in the following table:

Table 3.

Motor Rated 60 hertz Voltage	50 hertz Optional Voltage Ratings ($\pm 5\%$)		
230	190	200	208
460	380	400	415
575	475	500	—
Derate Factor	.85	.90	1.00

- Rated Hp at 50 Hz = Nameplate Hp x Derate Factor
- Allowable voltage variation at derated Hp = $\pm 5\%$
- Select motor overload protection for 60 Hz amps and

1.0 Service Factor

- Motor speed = 5/6 nameplate rated speed
- Service Factor = 1.0

60 Hz motors intended for use as shown above should be ordered as 60 Hz motors with no reference to 50 Hz operation.

A stick-on label containing the information shown in Table 3 is available.

DUAL FREQUENCY

Motors that require 50 and 60 Hz operation of the same motor are non-NEMA defined motors and will be nameplated as such. When this is a motor requirement, it must be specified with the order.

VARIABLE FREQUENCY OPERATION

Motors are available for use on variable frequency inverters of various types:

1. VVI is a square wave inverter in which voltage and frequency vary in proportion (constant volts per hertz).
2. PWI is a pulse width modulated inverter and the same as the VVI type except pulses are varied in time to simulate a sine wave.
3. CCI is a constant current inverter, which utilizes a square wave current supply as opposed to voltage.
4. IGBT is a pulse width modulated inverter using a bipolar transistor for higher switching speeds. This technology provides a cleaner resolved sine wave on a carrier frequency above the audible range.

When applying a motor for use with a variable frequency drive, see section on special applications.

POLYPHASE OR SINGLE-PHASE POWER

DEFINITION

A power system can be either single-phase or polyphase. Figure 4 illustrates single-phase power, which is most commonly found in homes, rural areas and in small commercial establishments.

A polyphase power system consists of two or more alternating currents of equal frequency and amplitude but offset from each other by a phase angle. Figure 5 illustrates a three-phase power system having phases A, B and C. Each phase is offset by 120 degrees, 360 degrees being the span of one complete cycle.

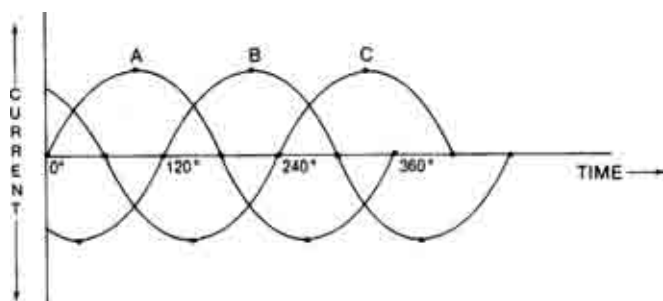


Figure 5. Three-phase Power

For motors, an advantage of three-phase power is simpler construction which requires less maintenance. Also, a more powerful machine can be built into a smaller frame and will generally operate at a higher efficiency than single-phase motors of the same rating.

MOTOR OUTPUT RATING

SPEED

The speed at which an induction motor operates is dependent upon the input power frequency and the number of electromagnetic poles for which the motor is wound. The higher the frequency, the faster the motor runs. The more poles the motor has, the slower it runs. The speed of the rotating magnetic field in the stator is called synchronous speed. To determine the synchronous speed of an induction motor, the following equation is used:

$$\text{Synchronous Speed (rpm)} = \frac{60 \times 2 \times \text{Frequency}}{\text{Number of poles}}$$

Actual full-load speed (the speed at which an induction motor will operate at nameplate rated load) will be less than synchronous speed.

The difference between synchronous speed and full-load speed is called slip. Percent slip is defined as follows:

$$\text{Percent Slip} = \frac{\text{Synchronous Speed} - \text{Full-Load Speed}}{\text{Synchronous Speed}} \times 100$$

Induction motors are built having rated slip ranging from less than 5% to as much as 20%. A motor with a slip of less than 5% is called a normal slip motor. Motors with a slip of 5% or more are used for applications requiring high starting torque (conveyor) and/or higher than normal slip (punch press) where, as the motor slows down, increased torque allows for flywheel energy release.

TORQUE & HORSEPOWER

Torque and horsepower are two key motor characteristics that determine the size of motor for an application. The difference between the two can be explained using a simple illustration of a shaft and wrench.

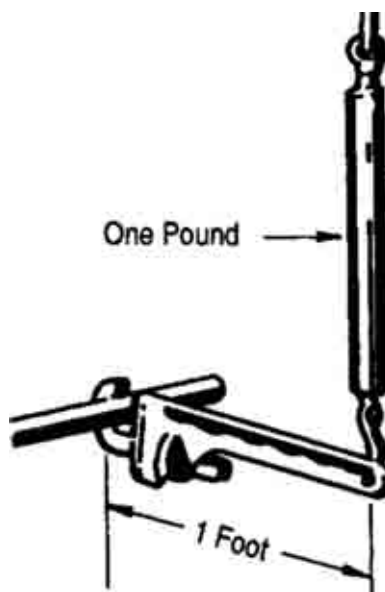


Figure 6.

Torque is merely a turning effort or force acting through a radius. In Figure 6 on page 4, it takes one pound at the end of the one foot wrench to turn the shaft at a steady rate. Therefore, the torque required is one pound times one foot, or one pound-foot. If the wrench were turned twice as fast, the torque required would remain the same, provided it is turned at a steady rate.

Horsepower, on the other hand, takes into account how fast the shaft is turned. Turning the shaft rapidly requires more horsepower than turning it slowly. Thus, horsepower is a measure of the rate at which work is done. By definition, the relationship between torque and horsepower is as follows:

$$1 \text{ Horsepower} = 33,000 \text{ lb-ft/minute}$$

In the above example, the one pound force moves a distance of 1 foot $\times 2\pi$ $\times$ 1 pound, or 6.28 feet per revolution. To produce one horsepower, the shaft would have to be turned at a rate of:

$$\frac{1 \text{ Hp} \times 33,000 \text{ lb-ft/min/Hp}}{1 \text{ lb} \times 2\pi \text{ ft/Revolution}} = 5252 \text{ RPM}$$

From the above, an equation is derived for determining horsepower output from speed and torque in lb-ft.

$$\text{Hp} = \frac{\text{RPM} \times 2\pi \times \text{Torque}}{33,000} \quad \text{or} \quad \text{Hp} = \frac{\text{RPM} \times \text{Torque}}{5252}$$

From this relationship:

$$\text{Full-load torque in lb-ft} = \frac{\text{Hp} \times 5252}{\text{Full-Load rpm}}$$

The following graph illustrates a typical speed torque curve for a NEMA design B induction motor. An understanding of several points on this curve will aid in properly applying motors.

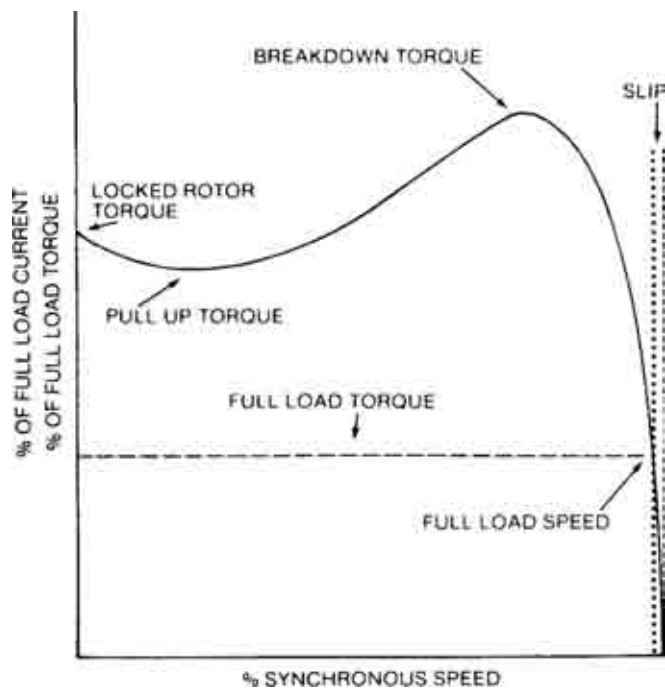


Figure 7. Speed Torque Curve

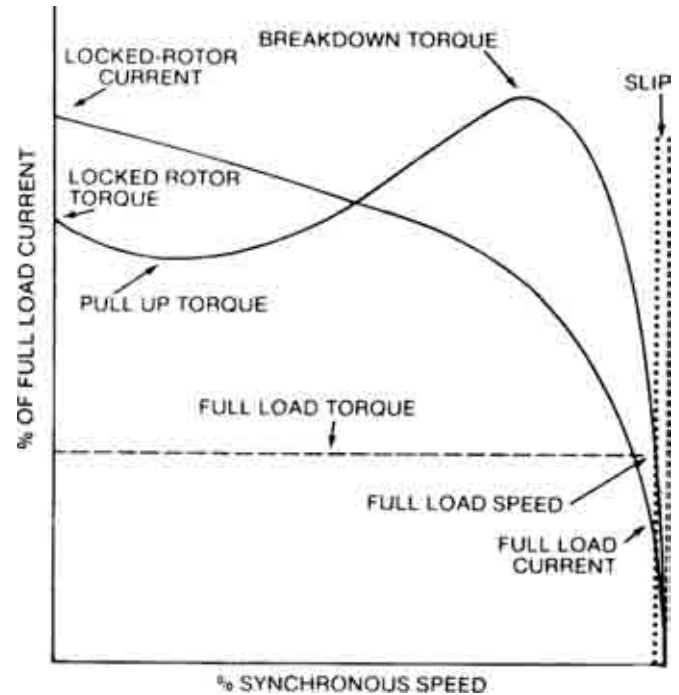


Figure 8. Speed, Torque, Current Curve

LOCKED-ROTOR TORQUE

Locked-rotor torque is the torque which the motor will develop at rest (for all angular positions of the rotor) with rated voltage at rated frequency applied. It is also sometimes known as starting torque and is usually expressed as a percentage of full-load torque.

PULL-UP TORQUE

Pull-up torque is the minimum torque developed during the period of acceleration from locked-rotor to the speed at which breakdown torque occurs. For motors which do not have a definite breakdown torque (such as NEMA design D) pull-up torque is the minimum torque developed up to rated full-load speed. It is usually expressed as a percentage of full-load torque.

BREAKDOWN TORQUE

Breakdown torque is the maximum torque the motor will develop with rated voltage applied at rated frequency without an abrupt drop in speed. Breakdown torque is usually expressed as a percentage of full-load torque.

FULL-LOAD TORQUE

Full-load torque is the torque necessary to produce rated horsepower at full-load speed. In pound-feet, it is equal to the rated horsepower times 5252 divided by the full-load speed in RPM.

MOTOR CURRENT

In addition to the relationship between speed and torque, the relationship of motor current to these two values is an important application consideration. The speed/torque curve is repeated below with the current curve added to demonstrate a typical relationship.

Two important points on this current curve need to be examined:

FULL-LOAD CURRENT

The full-load current of an induction motor is the steady-state current taken from the power line when the motor is operating at full-load torque with rated voltage and rated frequency applied.

LOCKED-ROTOR CURRENT

Locked-rotor current is the steady-state current of a motor with the rotor locked and with rated voltage applied at rated frequency. NEMA has designated a set of code letters to define locked-rotor kilovolt-amperes-per-horsepower. This code letter appears on the nameplate of all AC squirrel-cage induction motors. KVA per horsepower is calculated as follows:

For three-phase motors:

$$\text{KVA} = \frac{\sqrt{3} \times \text{current (in amperes)} \times \text{volts}}{1000 \times \text{Hp}}$$

For single-phase motors:

$$\text{KVA/HP} = \frac{\text{current (in amperes)} \times \text{volts}}{1000 \times \text{Hp}}$$

Table 4. Locked-Rotor Current Code Letters

Letter Designation	KVA per Hp*
A	0 - 3.15
B	3.15 - 3.55
C	3.55 - 4.0
D	4.0 - 4.5
E	4.5 - 5.0
F	5.0 - 5.6
G	5.6 - 6.3
H	6.3 - 7.1
J	7.1 - 8.0
K	8.0 - 9.0
L	9.0 - 10.0
M	10.0 - 11.2
N	11.2 - 12.5
P	12.5 - 14.0
R	14.0 - 16.0
S	16.0 - 18.0
T	18.0 - 20.0
U	20.0 - 22.4
V	22.4 and up

*The locked-rotor kilovolt-ampere-per-horsepower range includes the lower figure up to, but not including, the higher figure. For example, 3.14 is letter "A" and 3.15 is letter "B".

By manipulating the preceding equation for KVA/Hp for three-phase motors the following equation can be derived for calculating locked-rotor current:

$$LRA = \frac{1000 \times Hp \times \text{Locked-Rotor KVA/Hp}}{\sqrt{3} \times \text{Volts}}$$

This equation can then be used to determine approximate starting current of any particular motor. For instance, the approximate starting current for a 7.5 Hp, 230 volt motor with a locked-rotor KVA code letter G would be:

$$LRA = \frac{1000 \times 7.5 \times 6.0}{\sqrt{3} \times 230} = 113 \text{ amps}$$

Operating a motor in a locked-rotor condition in excess of 20 sec-onds can result in insulation failure due to the excessive heat generated in the stator. Figure 9 illustrates the maximum time a motor maybe operated at locked-rotor without injurious heating. This graph assumes a NEMA design B motor with a class B or F temperature rise.

POLYPHASE MOTORS, 1-200 HP

NEMA has designated several specific types of motors, each type having unique speed/torque relationships. These designs are described below along with some typical applications for each.

Following these descriptions is a summary of performance characteristics.

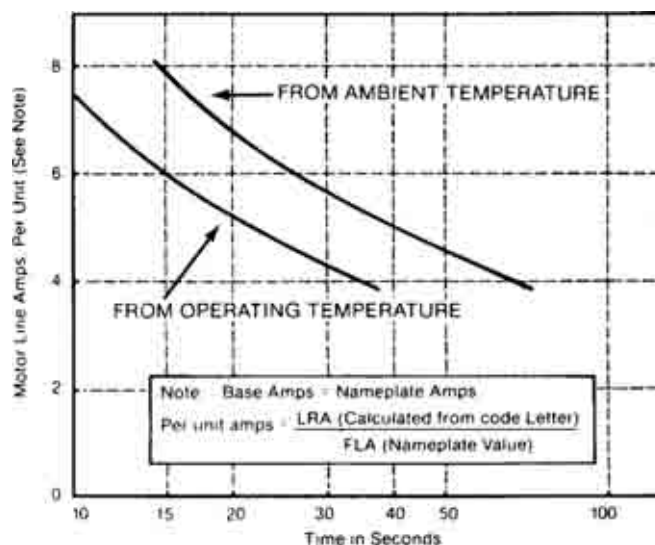


Figure 9. Line Current vs. Safe Stall Time for Standard Induction Motors

NEMA DESIGN A & B

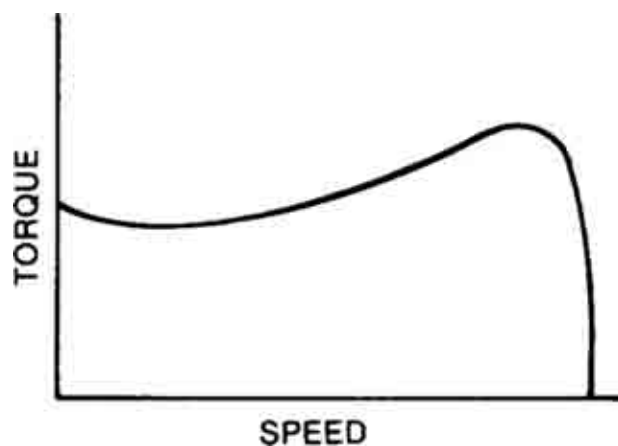


Figure 10. Typical NEMA Design A & B Speed/Torque Curve

GE Types:
Starting Current:

Starting Torque:
Breakdown Torque:
Full-Load Slip:
Applications:

K, KS, KE
Design A - High to Medium (not defined by NEMA)
Design B - Low Normal
Normal
Low (less than 5%)
Fans, blowers, pumps, machine tools, or other uses with low starting torque requirements and essentially constant load.

NEMA DESIGN C

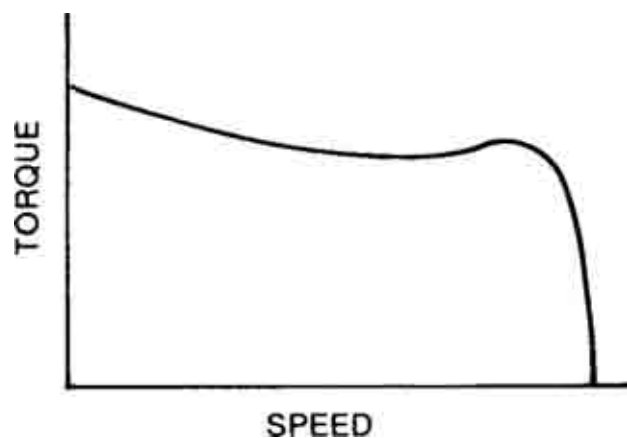


Figure 11. Typical NEMA Design C Speed/Torque Curve

NEMA DESIGN D

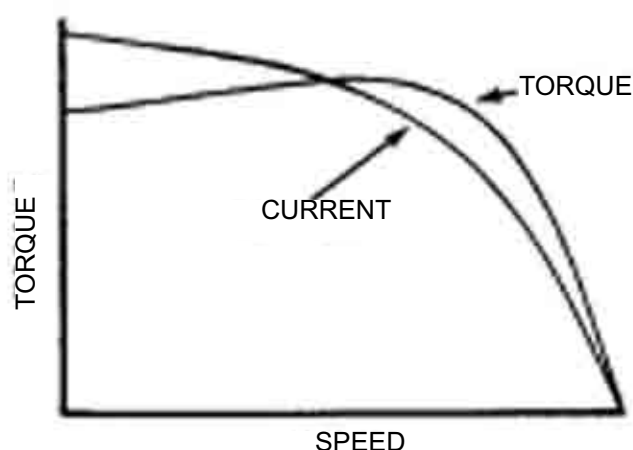


Figure 12. Typical NEMA Design D Speed/Torque Curve

GE Types: KG, KGS
 Starting Current: Low
 Starting Torque: High
 Breakdown Torque: Normal
 Full-Load Slip: Low (less than 5%)
 Applications: Hard-to-start loads such as plunger pumps, conveyors and compressors.

GE Type: KR
 Starting Current: Low
 Starting Torque: Very High
 Breakdown Torque: Not Applicable
 Full-Load Slip: High (5-8%; 8-13%)
 Applications: The combination of high starting torque and high slip make Type KR motors ideal for very high inertia loads and/or for considerable variations in load; e.g., punch presses, shears, cranes, hoists and elevators.

The following tables compare NEMA polyphase designs for several performance criteria.

Table 5. Comparison of Polyphase Designs

NEMA Design	Starting Current	Locked-Rotor Torque	Breakdown Torque	% Slip	Applications
A	High to Medium	Normal	Normal	Max 5%	Broad applications including fans, blowers, pumps, machined tools.
B	Low	Normal	Normal	Max 5%	Normal starting torque for fans, blowers, rotary pumps, unloaded compressors, some conveyors, metal cutting machine tools, misc. machinery. Constant load speed.
C	Low	High	Normal	Max 5%	High inertia starts such as large centrifugal blowers, flywheels and crusher drums. Loaded starts such as piston pumps, compressors and conveyors. Constant load speed.
D	Low	Very High	-	-	Very high inertia and loaded starts. Choice of slip to match load.
				5-8%	1) Punch presses, shears and forming machine tools.
				8-13%	2) Cranes, hoists, elevators and oil well pumping jacks.

LOCKED-ROTOR TORQUE

Table 6. Minimum Locked-rotor Torque - NEMA MG-1, Part 12 (% of Full-load Torque)

Hp	Design A and B							Design C			Design D		
RPM @ 60 Hz	3600	1800	1200	900	720	600	514	1800	1200	900	1800	1200	900
RPM @ 50 Hz	3000	1500	1000	750	—	—	—	1500	1000	750	1500	1000	750
1	—	275	170	135	135	115	110	—	—	—	275	275	275
1.5	175	250	165	130	130	115	110	—	—	—	275	275	275
2	170	235	160	130	125	115	110	—	—	—	275	275	275
3	160	215	155	130	125	115	110	—	250	225	275	275	275
5	150	195	150	130	125	115	110	250	250	225	275	275	275
7.5	140	175	150	125	120	115	110	250	225	200	275	275	275
10	135	165	150	125	120	115	110	250	225	200	275	275	275
15	130	160	140	125	120	115	110	225	200	200	275	275	275
20	130	150	135	125	120	115	110	200	200	200	275	275	275
25	130	150	135	125	120	115	110	200	200	200	275	275	275
30	130	150	135	125	120	115	110	200	200	200	275	275	275
40	125	140	135	125	120	115	110	200	200	200	275	275	275
50	120	140	135	125	120	115	110	200	200	200	275	275	275
60	120	140	135	125	120	115	110	200	200	200	275	275	275
75	105	140	135	125	120	115	110	200	200	200	275	275	275
100	105	125	125	125	120	115	110	200	200	200	275	275	275
125	100	110	125	120	115	115	110	200	200	200	275	275	275
150	100	110	120	120	115	115	—	200	200	200	275	275	275
200	100	100	120	120	115	—	—	200	200	200	—	—	—
250	70	80	100	100	—	—	—	—	—	—	—	—	—
300-350	70	80	100	—	—	—	—	—	—	—	—	—	—
400-500	70	80	—	—	—	—	—	—	—	—	—	—	—

PULL-UP TORQUE

The pull-up torque for NEMA design A and B motors listed in Table 6 with rated voltage and frequency applied will not be less than the following:

Table 7. Minimum Pull-up Torque - NEMA MG-1, Part 12

Design A and B Locked-rotor torque from Table 6.	Pull-up Torque
110% or less	90% of locked-rotor torque in Table 6.
Greater than 110% but less than 145%	100% of full-load torque in Table 6.
145% or more	70% of locked-rotor torque in Table 6.

The pull-up torque of Design C motors, with rated frequency and voltage applied, will not be less than 70 percent of the locked-rotor torque in Table 6.

BREAKDOWN TORQUE

See Table 8 on next page

POLYPHASE MOTORS LARGER THAN 500 HP

Ratings larger than those listed in Tables 6, 7 and 8 are not covered by NEMA design letters, but have minimum torques established by NEMA MG-1 as follows:

Table 9. Motor Torque - NEMA MG-1, Part 20

Torque	*Minimum % of Rated Full-Load Torque
Locked-Rotor	60
Pull-up	60
Breakdown	175

*Higher values can be quoted for specific applications.

Locked-rotor current of these designs will normally not exceed 650% of full-load current, and will normally be within NEMA locked-rotor KVA limits for a code G or H motor.

SINGLE-PHASE MOTORS

NEMA DESIGN L

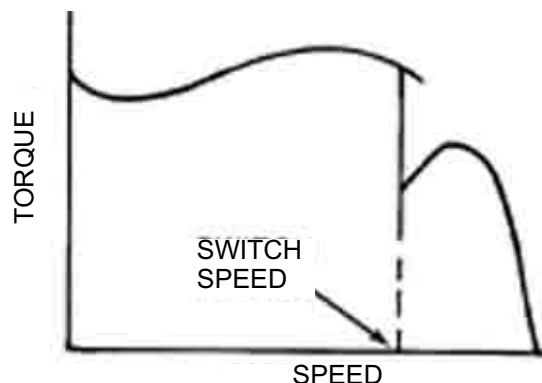


Figure 13. Typical NEMA Design L Speed/Torque Curve

Table 8. Minimum Breakdown Torque - NEMA MG-1, Part 12 (% of Full-Load Torque)

Hp	Design A and B							Design C		
	3600	1800	1200	900	720	600	514	1800	1200	900
FPM @ 60 Hz	3600	1800	1200	900	720	600	514	1800	1200	900
FPM @ 50 Hz	3000	1500	1000	750	-	-	-	1500	1000	750
1	-	300	285	215	200	200	200	-	-	-
1.5	250	280	250	210	200	200	200	-	-	-
2	240	270	240	210	200	200	200	-	-	-
3	230	250	230	205	200	200	200	-	225	200
5	215	225	215	205	200	200	200	200	200	200
7.5	200	215	205	200	200	200	200	190	190	190
10	200	200	200	200	200	200	200	190	190	190
15	200	200	200	200	200	200	200	190	190	190
20	200	200	200	200	200	200	200	190	190	190
25	200	200	200	200	200	200	200	190	190	190
30	200	200	200	200	200	200	200	190	190	190
40	200	200	200	200	200	200	200	190	190	190
50	200	200	200	200	200	200	200	190	190	190
80	200	200	200	200	200	200	200	190	190	190
75	200	200	200	200	200	200	200	190	190	190
100	200	200	200	200	200	200	200	190	190	190
125	200	200	200	200	200	200	200	190	190	190
150	200	200	200	200	200	200	-	190	190	190
200	200	200	200	200	200	-	-	190	190	190
250	175	175	175	175	-	-	-	-	-	-
300	175	175	175	-	-	-	-	-	-	-
350	175	175	175	-	-	-	-	-	-	-
400	175	175	-	-	-	-	-	-	-	-
450	175	175	-	-	-	-	-	-	-	-
500	175	175	-	-	-	-	-	-	-	-

A NEMA design L motor is a single-phase integral horsepower motor designed to withstand full-voltage starting. The GE offering to meet design limits of design L is a type KC. Starting performance of type KC motors is dependent upon an additional winding controlled by a centrifugal mechanism and switch. Upon energization of the motor, both windings and the run winding of the motor are connected to the line. As the motor comes up to speed, the centrifugal mechanism will actuate and open the switch, removing the start provisions from the line. The RPM at which this occurs is known as "switch speed". The motor will then operate at full-load with only the run windings connected.

Breakdown torques developed by Design L motors are shown in the following table:

Table 10. Single-phase (Design L) Breakdown Torque in lb-ft (NEMA MG-1, Part 10)

Hp	Frequency (hertz)					
	60	50	60	50	60	50
	Synchronous Speed					
	3600	3000	1800	1500	1200	1000
1	-	-	5.10-6.8	6.19-8.2	6.9-9.2	*
1.5	3.0-4.0	4.3-5.5	6.8-10.1	8.2-12.1	9.2-13.8	*
2	4.0-6.0	5.5-7.2	10.1-13.0	12.1-15.0	13.8-18.0	*
3	6.0-8.0	7.2-10.2	13.0-19.0	15.0-22.8	18.0-25.8	*
5	8.0-13.5	10.2-16.2	19.0-30.0	22.8-36.0	25.8-40.5	*
7.5	13.5-20.0	16.2-24.0	30.0-45.0	36.0-54.0	40.5-60.0	*
10	20.0-27.0	24.0-32.4	45.0-60.0	54.0-72.0	*	*

* No torque values have been established for these ratings.

Maximum locked-rotor currents for Design L, 60 Hz motors are shown in the following table:

Table 11. Single-phase Maximum Locked-Rotor Current in Amperes at 230 Volts - NEMA MG-1, Part 12

Hp	amps
1	45
1.5	50
2	65
3	90
5	135
7.5	200
10	200

SERVICE FACTOR

Service factor is defined as the permissible amount of overload a motor will handle within defined temperature limits. When voltage and frequency are maintained at nameplate rated values, the motor may be overloaded up to the horsepower obtained by multiplying the rated horsepower by the service factor shown on the nameplate. However, locked-rotor torque, locked-rotor current and breakdown torque are unchanged. NEMA has defined service factor values for standard polyphase dripproof, 60 Hz motors as shown in the following table:

Table 12. Service Factor

Hp	Synchronous Speed, rpm						
	3600	1800	1200	900	720	600	514
1	1.25	1.15*	1.15*	1.15*	1.0	1.0	1.0
1.5 - 125	1.15*	1.15*	1.15*	1.15*	1.15*	1.15*	1.15*
150	1.15*	1.15*	1.15*	1.15*	1.15*	1.15*	1.0
200	1.15*	1.15*	1.15*	1.15*	1.15*	1.0	1.0
Over 200	1.0	1.0	1.0	1.0	1.0	1.0	1.0

* These service factors apply only to NEMA design A, B and C motors.

MOTOR TEMPERATURE

A major consideration in both motor design and application is heat.

Excessive heat will accelerate motor insulation deterioration and cause premature insulation failure. Excessive heat may also cause a breakdown of bearing grease, thus damaging the bearing system of a motor.

The total temperature a motor must withstand is the result of two factors: external, or ambient temperature; and internal, or motor temperature rise. An understanding of how these components are measured and expressed is important for proper motor application.

For a given application, the maximum sustained ambient temperature, measured in degrees Centigrade (Celsius), should be determined.

Most motors are designed to operate in a maximum ambient temperature of 40°C. If the ambient temperature exceeds 40°C, the motor may need to be modified to compensate for the increase in total temperature.

The temperature rise is the result of heat generated by motor losses during operation. At no-load, friction in the bearings, core losses (eddy current and hysteresis losses), and stator I²R losses contribute to temperature rise; at full-load, additional losses which cause heating are rotor I²R losses and stray load losses. (NOTE: I = current in amps and R = resistance of the stator or rotor in ohms).

Since current increases with an increase in motor load and under locked-rotor, temperature rise will be significantly higher under these conditions. Therefore, applications requiring frequent starting and/or frequent overloads may require special motors to compensate for the increase in total temperature.

MOTOR COOLING

Since the total temperature of a motor is greater than the surrounding environment, heat generated during motor operation will be transferred to the ambient air. The rate of heat transfer affects the maximum load and/or the duty cycle of a specific motor design. Factors affecting this rate of transfer are:

1. Motor enclosure

Different enclosures result in different airflow patterns which alter the amount of ambient air in contact with the motor.

2. Frame surface area

Increasing the area of a motor enclosure in contact with the ambient air will increase the rate of heat transfer. General Electric motor enclosures often are cast with many ribs to increase their surface area for cooler operation.

3. Airflow over motor

The velocity of air moving over the enclosure affects the rate of heat transfer. Fans are provided on most totally enclosed

and some open motors to increase the velocity of air over the external parts.

4. Ambient air density

A reduction in the ambient air density will result in a reduction of the rate of heat transfer from the motor. Therefore, total operating temperature increases with altitude. Standard motors are suitable for operation up to 3300 feet; motors with service factor may be used at altitudes up to 9900 feet at 1.0 service factor.

INSULATION CLASS VS. TEMPERATURE

NEMA has classified insulation systems by their ability to provide suitable thermal endurance. The total temperature is the sum of ambient temperature plus the motor's temperature rise. The following charts illustrate the maximum total motor temperature allowed for each of the standard classes of insulation. An additional 10 degrees C measured temperature rise is permitted when temperatures are measured by detectors embedded in the winding. Figures 15-17 illustrate the temperature rise limits established for various insulation classes per NEMA MG-1, Part 12.

ENCLOSURE: DRIPPROOF OR TEFC SERVICE FACTOR: 1.0

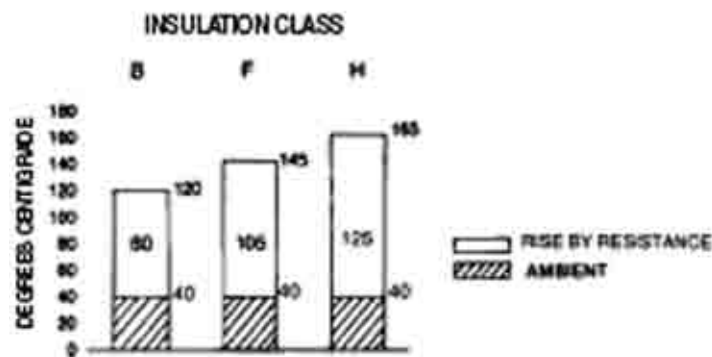


Figure 15.

ENCLOSURE: TENV SERVICE FACTOR: 1.0

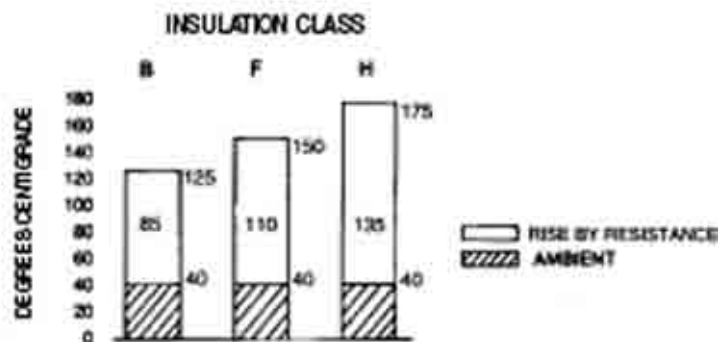


Figure 16.

ENCLOSURE: DRIPPROOF OR TEFC
SERVICE FACTOR: 1.15

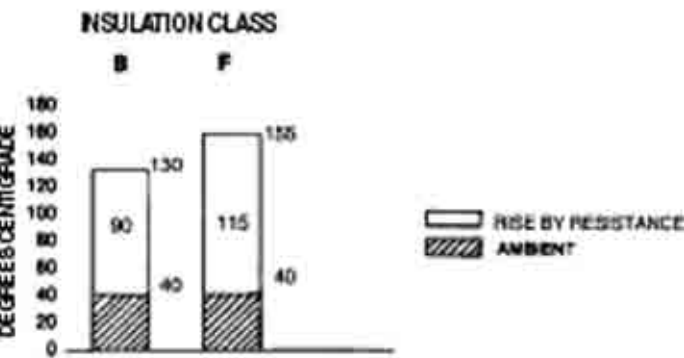


Figure 17.

DUTY CYCLE APPLICATIONS

TYPES OF DUTY

The duty cycle of a motor describes the energization/de-energization, and load variations, with respect to time for any given application.

Duty cycle applications may be divided into three basic classifications:

1. Continuous duty is a requirement of service that demands operation at an essentially constant load for an indefinitely long time.

This is the most common duty classification and accounts for approximately 90% of motor applications. To size a motor for a specific application with this duty cycle classification, select proper horsepower based upon continuous load.

2. Intermittent duty is a requirement of service that demands operation for alternate intervals of load and no-load; or load and rest; or load, no-load and rest; each interval of which is definitely specified. Select a motor for these applications to match the horsepower requirements under the loaded condition. In some instances, such as a hoist or elevator application, savings in the purchase price of a motor may be possible by designing for the intermittent duty cycle. 30 or 60 minute motors are normally specified.

Frequent starts, however, can increase motor heating.

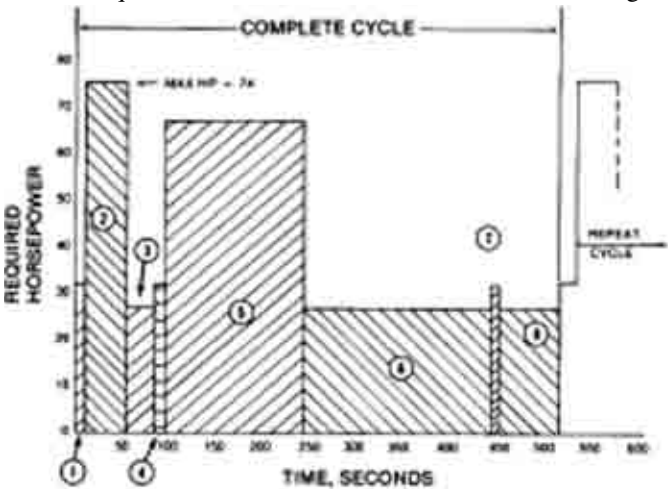


Figure 18. Duty Cycle Calculation

3. Varying duty is a requirement of service that demands operation at loads and for intervals of time, which may be subject to wide variation. For this classification of duty cycle, a horsepower versus time curve will permit determination of the peak horsepower required and a calculation of the root-mean-square (RMS) horsepower will indicate the proper motor rating from a heating standpoint. The following example demonstrates the method for selecting a motor for a varying duty cycle based upon peak horsepower and RMS horsepower requirements assuming constant frequency.

To properly size a motor for the varying duty cycle described in the preceding horsepower versus time graph, a table should be made as shown quantifying each part of the cycle. The first three columns of this table list data from the graph, and the fourth column is derived by squaring the horsepower and multiplying by the time for each part of the cycle. Using this data, sum the periods of time and (Hp)2t, and evolve the RMS horsepower as follows:

Table 12.

Part of Cycle	Time Sec. (t)	Required Hp	(Hp)2t
1	15	32	15,360
2	40	74	218,040
3	30	27	21,870
4	5	32	5,120
5	148	66	644,688
6	200	27	145,800
7	12	32	12,288
8	70	27	51,030
	520		1,115,200

$$RSM Hp = \sqrt{\frac{\sum (Hp)^2 t}{\sum t}}$$

RMS Hp = Root-Mean-Square Horsepower

$$RMS Hp = \sqrt{\frac{1,115,200}{520}} = \sqrt{2145} = 46.3 Hp$$

The load RMS horsepower is used to determine the required motor thermal capability at constant speed. To allow for ±10% voltage variation and the resulting additional motor heating, particularly at peak loads and 90% voltage, a 10% allowance is added to the RMS horsepower calculation:

$$\begin{aligned} \text{Required Hp} &= RMS Hp \times 1.10 \\ &= 46.3 \times 1.10 = 50.9 Hp \end{aligned}$$

The motor usable horsepower is determined by the nameplate Hp x service factor and must be equal to or greater than the required horsepower.

In our example, there is a choice of either a 50 Hp motor with a 1.15 service factor or a 60 Hp motor at a 1.0 service factor. From a thermal viewpoint, either of these ratings is suitable for the required load Hp of 50.9.

The motor must also be capable of carrying the peak horsepower (torque) value from the duty cycle at 90% voltage.

Since motor breakdown torque is reduced by the voltage squared, the required breakdown torque (BDT) is determined by the equation:

$$\%BDT = \left[\frac{\text{Peak-Load Hp} \times 100}{\text{NP Hp} \times .9^2} \right] + 20 \text{ (see note)}$$

$$= \left[\frac{\text{Peak-Load Hp} \times 123}{\text{NP Hp}} \right] + 20$$

NP Hp = Nameplate Rated Horsepower
%BDT = Percent Breakdown Torque

NOTE: Margin of 20% added to prevent inefficiencies of operation too close to actual breakdown torque.

For example, with a 50 Hp motor at 1.15 SF:

$$\%BDT = [74/50 \times 123 + 20] = 202\%$$

For 60 Hp at 1.0 SF:

$$\%BDT = [74/60 \times 123 + 20] = 172\%$$

Conclusion: Since the NEMA breakdown torque for a 50 Hp or 60 Hp motor is 200%, the best choice for the application is the 60 Hp rating which only requires 172% at the peak-load horsepower.

STARTING LOAD INERTIA (WK2)

In any type of duty cycle operation, it is necessary to determine not only the horsepower requirements but the number of times the motor will be started, the inertia of the driven machine, the type of load (constant or variable torque) and the method of stopping the motor.

The inertia (WK2) of the rotating parts of the driven equipment affects the acceleration time and motor heating during acceleration. The heating of motor rotor and stator during frequent starting, stopping, and/or reversals can become a design limitation.

If the motor is direct connected, the inertia supplied by the equipment manufacturer may be used as is. If the motor is to drive the equipment through a pulley or gear such that the driven equipment is operating at a higher or lower speed than the motor, it is necessary to calculate the inertia referred to the motor shaft; that is, an equivalent inertia based on the speed of the motor.

WK2 (Referred to Motor Shaft) =

$$\text{WK}^2 \text{ (Driven Equipment)} \times \frac{\text{RPM}^2 \text{ (Driven Equipment)}}{\text{RPM}^2 \text{ (Motor)}}$$

The method of stopping the motor is also taken into consideration in a duty cycle calculation. For example, if the motor is allowed to coast to a stop or mechanical braking is used, the RMS horsepower calculation may be affected. Plug stopping or DC braking increases motor heating considerably. Therefore, the method of stopping must be part of the duty cycle data provided.

STARTING FREQUENCY

A special kind of duty cycle is one in which a motor is required to perform repetitive starts with a given load and connected inertia. Motor selection must take into account the motor

heating caused by starting frequency, load inertia and running load.

A motor during acceleration draws about 6 times full-load current, so resistance losses during starting are up to 36 times (current squared) the losses at full-load. A motor operating on a low inertia load (pump) may come up to speed very quickly, in less than one second. Starting losses may be so low that the start cycle could be repeated several times per minute without overheating the winding. However, motor life can be limited by mechanical starting stresses. When frequent starting is planned refer to NEMA MG-10.

HIGH INERTIA LOADS

At the other extreme, the same motor connected to a high inertia load (such as a large centrifugal blower) could burn out before getting up to full speed on the first start. Motor applications involving frequent starts or high load inertia must be carefully studied to obtain satisfactory operation and long motor life.

The following table lists recommended maximum load inertias for type K, KG, KS and KGS, 60 or 50 Hz, motors starting a fan or centrifugal pump load for two successive cold starts or one start from rated load temperature. The cold starts should be possible within 10 seconds of each other at rated frequency and voltage, and permitted by conventional control. It is recommended, however, that high inertia drives have thermal protection in the motor to prevent burnout from misapplication or excessive starting frequency.

Table 13. Maximum Load Inertia
NEMA MG-1, Parts 12 and 20

Hp	Speed, RPM						
	3600	1800	1200	900	720	600	514
Load WK2 (Exclusive of Motor WK2) lb-ft ²							
1	—	5.8	15	31	53	82	118
1.5	1.8	8.0	23	45	77	120	174
2	2.4	11	30	60	102	158	228
3	3.5	17	44	87	149	231	335
5	5.7	27	71	142	242	375	544
7.5	8.3	39	104	208	350	551	798
10	11	51	137	273	457	723	1048
15	16	75	200	400	685	1061	1538
20	21	99	262	525	898	1393	2018
25	26	122	324	647	1108	1719	2491
30	31	144	384	769	1316	2042	2959
40	40	189	503	1007	1725	2677	3881
50	49	232	620	1241	2127	3302	4788
60	58	275	735	1473	2524	3819	5580
75	71	338	904	1814	3111	4831	7010
100	92	441	1181	2372	4070	6320	9180
125	113	542	1452	2919	5010	7790	11310
150	133	640	1719	3456	5940	9230	—
200	172	831	2238	4508	7750	12000	—
250	210	1017	2744	5540	9530	14830	—
300	246	1197	3239	6540	11270	—	—
350	281	1373	3723	7530	—	—	—
400	315	1546	4199	8500	—	—	—
450	349	1714	4666	9450	—	—	—
500	381	1880	5130	—	—	—	—
600	443	2202	6030	—	—	—	—
700	503	2514	—	—	—	—	—
800	560	2815	—	—	—	—	—

EFFICIENCY

DEFINITION

Efficiency is an important application consideration. That is especially true for applications having high hours of operation where cost of motor operation is many times the initial purchase price of the motor.

As shown below, efficiency is defined as watts output over watts input using 746 watts as the equivalent of one horsepower:

$$\text{Efficiency} = \frac{746 \times \text{Hp Output}}{\text{Watts Input}} = \frac{\text{Watts Output}}{\text{Watts Input}}$$

This can also be expressed as the watts input minus the losses divided by the watts input.

$$\text{Efficiency} = \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

The only way to improve efficiency is to reduce losses. Although input power is readily measured, power out is difficult to measure accurately. Therefore, precision equipment is required to determine the efficiency and the losses in a motor. Standard test procedures are defined to measure the individual components of loss separately in order to improve the accuracy of efficiency determination.

DESCRIPTION OF MOTOR LOSSES

Typically, motor losses are categorized, first, as those which occur while the motor is energized but operating at no-load; and, second, those additional losses due to the output load. Specific losses are:

1. No-load losses
 - a. Windage and friction
 - b. Stator iron losses
 - c. Stator I²R losses
2. Load Losses
 - a. Stator I²R losses (due to increase in current under load)
 - b. Rotor I²R
 - c. Stray load losses

The no-load losses and the conductor losses under load can be measured separately, however, the stray load loss requires accurate input-output test equipment for determination. The stray-load loss consists of losses due to harmonic currents and flux in the motor.

Factors affecting stray load losses include:

- Stator and rotor slot geometry
- Number of slots
- Air gap length
- Rotor slot insulation
- Manufacturing process

ENERGY POLICY ACT (EPACT)

GE Industrial Systems has noted all EPACT items as "KE" in the model numbering system. These models meet or exceed the EPACT law as stated in this table.

Table 13A. Nominal Efficiency Levels Covered by EPACT

Motor Hp	Enclosed Motors			Open Motors		
	6 pole	4 pole	2 pole	6 pole	4 pole	2 pole
1	80.0	82.5	75.5	80.0	82.5	—
1.5	85.5	84.0	82.5	84.0	84.0	82.5
2	86.5	84.0	84.0	85.5	84.0	84.0
3	87.5	87.5	85.5	86.5	86.5	84.0
5	87.5	87.5	87.5	87.5	87.5	85.5
7.5	88.5	88.5	88.5	88.5	88.5	87.5
10	89.5	89.5	89.5	90.2	89.5	88.5
15	90.2	91.0	90.2	90.2	91.0	89.5
20	90.2	91.0	90.2	91.0	91.0	90.2
25	91.7	92.4	91.0	91.7	91.7	91.0
30	91.7	92.4	91.0	92.4	92.4	91.0
40	93.0	93.0	91.7	93.0	93.0	91.7
50	93.0	93.0	92.4	93.0	93.0	92.4
60	93.0	93.0	93.0	93.0	93.0	93.0
75	93.0	94.1	93.0	93.0	94.1	93.0
100	94.1	94.5	93.0	94.1	94.1	93.0
125	94.1	94.5	94.5	94.1	94.5	93.0
150	95.0	95.0	94.5	94.5	95.0	93.0
200	95.0	95.0	95.0	94.5	95.0	94.5

The following motor products are currently exempt from U.S. and Canadian legislation:

NEMA C and D Designs	Single Phase
200 and 575 Volt	Direct Current (DC)
Multispeed	Totally-Enclosed Air-Over
Integral Brake Motors	Totally-Enclosed Non Vent
Motors Above 200 or Below 1 Hp	Close Coupled Pump (JM/JP) 50 Hertz

The Canadian Energy Act parallels the U.S. law with some specific differences. The Canadian legislation includes:

200 and 575 Volt
Integral Brake Motors
50 Hz Motors

MOTOR TESTING

Good motor application practice requires that uniform and meaningful terminology be used to define efficiency values which are determined by accurate test procedures uniformly applied by the motor manufacturers.

Testing to accurately determine the value of motor losses can be time consuming and expensive. Also, wide variations in results can be experienced when different test methods are used. In order to maintain consistency, NEMA has established the following guidelines:

Efficiency and losses shall be determined in accordance with the latest revision of IEEE standard 112. Polyphase squirrel-cage motors rated 1-125 Hp shall be tested by dynamometer, Method B.

The efficiency will be determined using segregated losses in which stray load loss is obtained from a linear regression

analysis to reduce the effect of random errors in the test measurements.

This procedure focuses on stray load losses where the greatest variance can occur from one motor to the next. It also clearly defines the procedure and requires testing either at full operating temperature or by making corrections for temperature differences. Finally, test method B requires use of a dynamometer to provide the most accurate data as a basis for accuracy improvement and stray load loss measurement.

Motor efficiency is not an absolute or constant for all motors of the same design. Rather, the efficiencies of a large number of motors will fit a normal distribution or "bell" curve as shown in Figure 19.

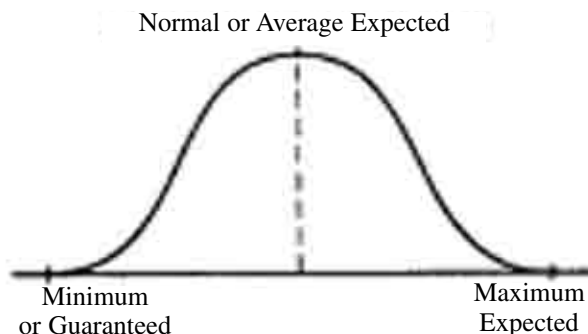


Figure 19. Efficiency Distribution

The nominal efficiency which appears on the motor nameplate corresponds to the nominal, or average expected efficiency on the curve.

The guaranteed minimum efficiency appearing on GE energy efficient motor nameplates corresponds to the minimum, or guaranteed on the curve.

POWER FACTOR

In a sense, motors are electromagnets and power factor is a measure of the amount of magnetizing current required.

Power factor is an important consideration when selecting a motor for a particular application, since low power factor may result in power factor penalty charges from the utility company. Since the power company must supply KVA but normally meters only kilowatts used, low motor power factor requires additional KVA with low return on KW utilized; hence, power factor penalties.

Following is the equation for power factor in a three-phase system:

$$\text{Amps} = \frac{\text{Watts Input}}{\sqrt{3} \times \text{Volts} \times \text{PF}}$$

This equation is a numerical method of expressing the phase difference between voltage and current in a motor circuit. The current in an induction motor lags the applied voltage, and only the component that is in phase with the voltage varies with motor power. The relationship expressed in the above equation can be shown as a vector relationship in which the numerical expression is actually the cosine of the angle L.

As seen from their relationship, line current required for a given motor output varies inversely with power factor.

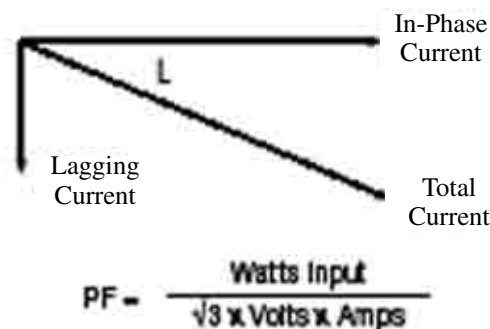


Figure 20.

Increasing power factor will reduce required line current, thus reducing voltage drop in power lines and transformers.

The lagging current shown above is actually motor magnetizing current, which is dependent upon motor design. This magnetizing current is independent of motor load; i.e., just as much is required at no-load as at full-load. Thus power factor at partial loads is never as high as at full-load, and at no-load power factor is essentially zero.

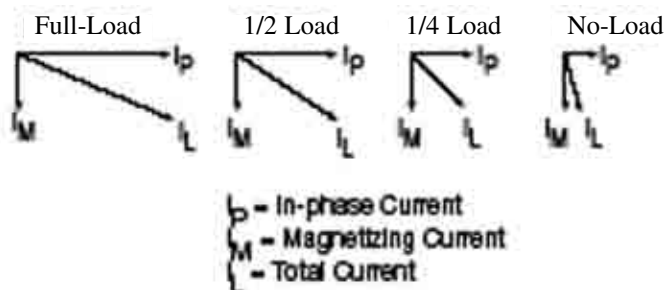


Figure 21.

There are two basic methods for improving the power factor of a motor for a particular application:

1. Purchase a motor with an inherently high power factor.
2. Install power factor correction capacitors. Capacitors draw leading current as opposed to the lagging current drawn by induction motors. Placing capacitors in parallel with the motor windings will result in leading current offsetting some of the lagging current, increasing power factor as shown in Figure 22:

For many applications the use of capacitors for power factor correction is the most economical method and one that also works at partial loads. Capacitors should be used to improve full-load power factor to approximately 95% maximum.

WARNING: IN NO CASE SHOULD POWER FACTOR IMPROVEMENT CAPACITORS BE APPLIED IN RATINGS EXCEEDING THE MAXIMUM SAFE VALUE SPECIFIED BY THE MOTOR MANUFACTURER. EXCESSIVE IMPROVEMENT MAY CAUSE OVER EXCITATION RESULTING IN HIGH TRANSIENT VOLTAGES, CURRENTS AND TORQUES THAT CAN INCREASE SAFETY HAZARDS TO PERSONNEL AND CAUSE POSSIBLE DAMAGE TO THE MOTOR OR TO THE DRIVEN EQUIPMENT.

Without Capacitors

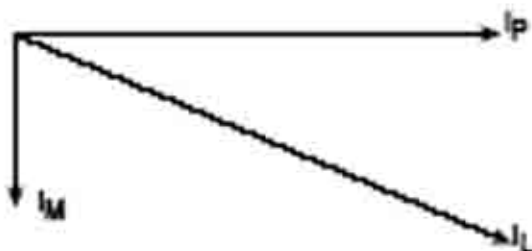
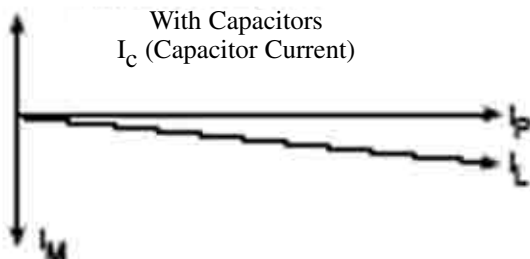
With Capacitors
 I_C (Capacitor Current)

Figure 22.

LOAD CONNECTION

TYPES OF CONNECTION

Two methods of mechanical connection of the motor to the driven load are commonly used:

1. Direct Connection

Direct connection should always be considered where the required load speed coincides with an available motor speed. The preferred practice is to use a flexible coupling which will allow a slight amount of misalignment and minimize transmission of thrust to the motor bearings. Axial thrust loads are commonly encountered when a pump impeller or fan is mounted on the motor shaft.

They also occur in direct connected helical gear drives and when the motor is mounted vertically or in an inclined position where any weight other than the rotor is supported by the motor shaft.

Refer to Table 14 for recommended maximum axial thrust loads for horizontal ball-bearing motors with typical bearing sizes.

2. Belt, chain and gear drives

When connecting a motor to its load with this type of drive, proper selection is necessary to limit bearing loads within radial load capacities. Tables 15 and 15A provide recommended minimum V-belt sheave diameters for 60 and 50 Hz motors. Tables 15 and 15A indicate the approximate radial forces corresponding to a belt tightened sufficiently to prevent slippage. Additional tension will increase the radial force and decrease bearing life. For A-BC-D-E belts, the center line of the pulley should not extend beyond the end of the shaft. For 3V-5V-8V belts, the centerline of the pulley should not be any closer to the end of the shaft than 1/2 the V dimension of the shaft.

At times, requests are made for parameters not labeled in these tables. Belt and sheave manufacturers and their distributors typically provide a Load Analysis Data Sheet as a technical service.

Table 14. Axial Thrust (pounds) for Horizontal Motors

Frame	3600 RPM		1800 RPM		1200 RPM		900 RPM	
	Brg	Thrust	Brg	Thrust	Brg	Thrust	Brg	Thrust
182-184	0208	140	0208	105	0208	220	0208	245
213-215	0307	250	0307	335	0307	375	0307	425
254-256	0308	405	0308	500	0308	670	0308	710
284-286	0310	400	0310	625	0310	770	0310	790
324-326	0210	230	0210	290	0210	395	0210	325
364-366	0213	390	0213	485	0213	630	0213	635
404-406	0313	375	0213	435	0213	590	0213	710
444-446	0314	700	0314	1040	0314	1205	0314	1400
449	0314	705	0314	905	0314	1115	0314	1325
509	0315	705	0318	1175	0318	1275	0318	1445
511	0315	680	0318	1030	0318	1290	0318	1260
513	0315	620	0320	1205	0320	1360	0320	1450

NOTE: Table 14 assumes no external radial loading on the shaft. Thrust values in Table 14 represent the maximum permissible to provide a 25,000 hour L₁₀ life in accordance with AFEMA calculations.

Table 15. Limiting Sheave Dimensions for V-Belt Drive
(Frames 182T - 449T)

Frame	Horsepower at Sync. Speed, RPM				V-Belt Sheave (Inches)			
					Conventional and E Sections		Narrow 3V, 5V and 8V Sections	
	60 Hz	3600	1800	1200	600	HP	HP	HP
182T	3	3	1.5	1	2.4	5.25	2.4	2.75
182T	5	-	-	-	2.6	5.25	2.4	2.75
184T	-	-	2	1.5	2.4	5.25	2.4	2.75
184T	5	-	-	-	2.6	5.25	2.4	2.75
184T	7.5	5	-	-	3.0	5.25	3.0	2.75
213T	7.5-10	7.5	3	2	3.0	6.5	3.0	3.38
215T	10	-	5	3	3.0	6.5	3.0	3.38
215T	15	10	-	-	3.8	6.5	3.8	3.38
254T	15	-	7.5	5	3.8	7.75	3.8	4.0
254T	20	15	-	-	4.4	7.75	4.4	4.0
256T	20-25	-	10	7.5	4.4	7.75	4.4	4.0
256T	-	20	-	-	4.6	7.75	4.4	4.0
284T	30	-	-	-	4.4	9.0	4.4	4.58
284T	-	-	15	10	4.6	9.0	4.4	4.58
284T	-	25	-	-	5.0	9.0	4.4	4.58
286T	30	-	-	-	4.4	9.0	4.4	4.58
286T	40	-	-	-	4.6	9.0	4.6	4.58
286T	-	30	20	15	5.4	9.0	5.2	4.58
324T	40	-	-	-	4.6	10.3	4.6	5.25
324T	-	40	25	20	5.0	10.3	5.0	5.25
324T	50	-	-	-	5.0	10.3	5.0	5.25
326T	50	-	-	-	5.0	10.3	5.0	5.25
326T	-	50	30	25	5.8	10.3	5.8	5.25
326T	60	-	-	-	5.4	10.3	5.4	5.25
364T	-	-	40	30	5.8	11.5	5.8	5.88
364T	60	-	-	-	5.4	11.5	5.4	5.88
364T	-	60	-	-	7.4	11.5	7.4	5.88
366T	-	-	50	40	8.2	11.5	8.2	5.88
366T	-	75	-	-	9.0	11.5	8.6	5.88
404T	-	-	60	-	9.0	14.3	8.6	7.25
404T	-	-	-	50	9.0	14.3	8.4	7.25
404T	-	100	-	-	10.0	14.3	8.6	7.25
406T	-	-	75	60	10.0	14.3	10.0	7.25
406T	-	100	-	-	10.0	14.3	8.6	7.25
406T	-	125	-	-	11.5	14.3	10.5	7.25
444T	-	-	100	-	11.0	16.8	10.0	8.5
444T	-	-	-	75	10.5	16.8	9.5	8.5
444T	-	125	-	-	11.0	16.8	9.5	8.5
444T	-	150	-	-	-	-	10.5	8.5
445T	-	-	125	-	12.5	16.8	12.0	8.5
445T	-	-	-	100	12.5	16.8	12.0	8.5
445T	-	150	-	-	-	-	10.5	8.5
445T	-	200	-	-	-	-	13.2	8.5
445T	-	-	150	-	-	-	13.5	8.5
449T	-	-	200	-	-	-	18.75	8.5
449T	-	-	-	150	-	-	19.0	8.5
449T	-	-	-	200	-	-	27.75	8.5
449T	-	250	-	-	-	-	15.5	12.8

* Applicable to motors with long T shaft only.
™ Force for highest torque rating.
NOTE: The recommended sheave diameters are based on a 5:1 speed reduction, and a pulley center-to-center distance approximately equal to the diameter of the larger sheave. Shaft extension is the minimum required by NEMA (Table MG-1 11.31)
Sheave diameter is minimum required by NEMA (Table 14-1) for narrow V-belt sections.

Table 15A. Limiting Sheave Dimensions for V-Belt Drive
Typical 500 Frame Data

Dripproof					
Horsepower @ RPM			Brg. Const.	Min. Sheave Dia. (in.)	Belt Pull (lbs.)
1800	1200	900			
-	-	150	(1)	10.5	2200
-	-	200	(2)	9	5500
-	-	250	(2)	17	3600
-	250	-	(2)	9	5200
-	300	-	(2)	15	3700
300	-	-	(2)	7.5	4900
350	-	-	(2)	13.5	3200
TEFC Motors					
-	-	125	(1)	14.5	2100
-	-	150	(1)	18	2100
-	-	200	(2)	13	3800
-	200	-	(1)	18	2100
-	250	-	(2)	15	3100
-	250*	-	(2)	10.5	4400
250	-	-	(1)	17.5	1800
300	-	-	(2)	9	4100
350	-	-	(2)	11.5	3800

* for 5011 L frame size.
(1) Deep groove ball-bearing construction
(2) Special shaft materials and roller-bearing construction.

- NOTE:
- 1. Minimum bearing life, L10, for a given sheave diameter is 25,000 hours.
 - 2. The recommended sheave diameters are based on a 5:1 speed reduction and a sheave center-to-center distance approximately equal to the diameter of the larger sheave.

CAUTION: BELT SPEEDS IN EXCESS OF 6500 FEET PER MINUTE MAY REQUIRE SPECIAL SELECTION OF DRIVE COMPONENTS. MOTOR USER SHOULD GET SPECIFIC APPROVAL FROM BELT AND SHEAVE SUPPLIER FOR SUCH APPLICATIONS.

LOAD CALCULATIONS

BELT DRIVEN APPLICATION ANALYSIS

Belt and sheave manufacturers and their distributors typically provide a Load Analysis Data Output Sheet to the end user/OEM as a technical service. When requesting a quotation for GE Industrial Systems, we suggest that the Load Analysis Data Output Sheet be provided in addition to this form for a complete motor shaft and bearing analysis.

ELECTRICAL CONSTRUCTION

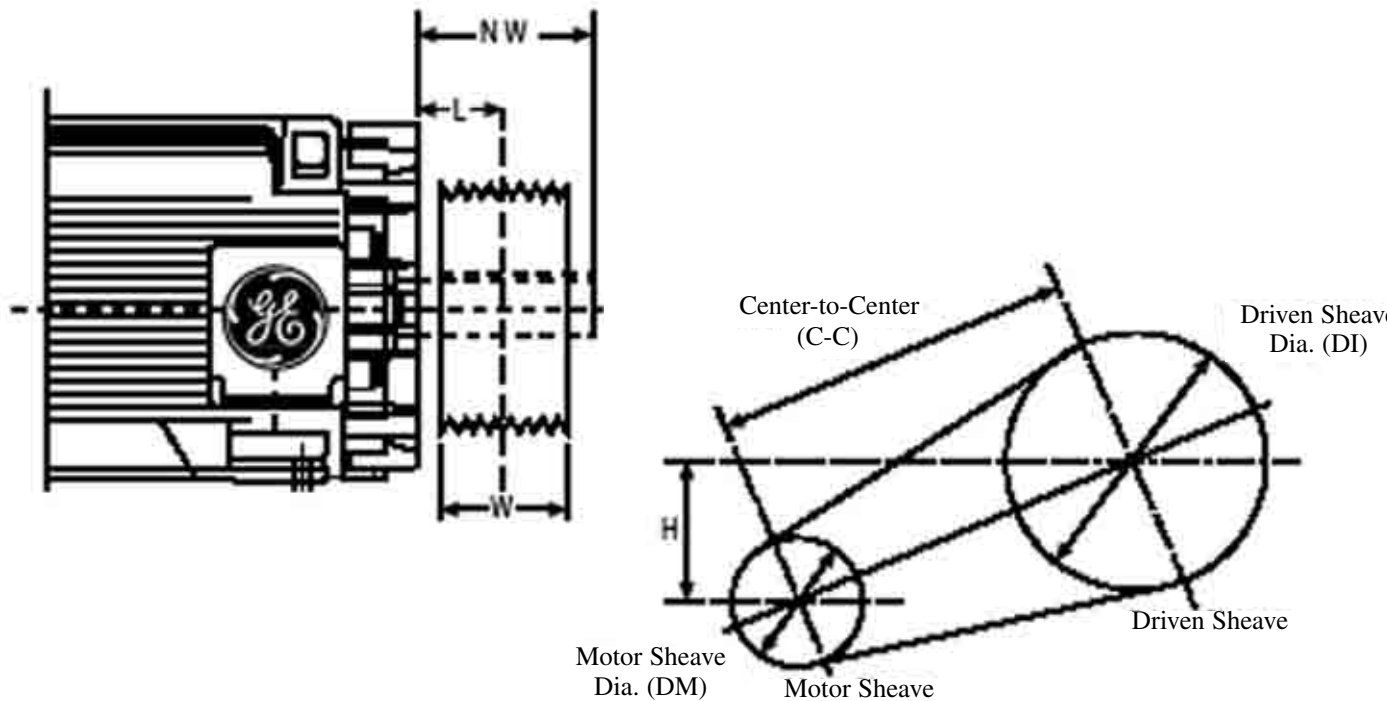
WINDING CONNECTIONS AND STARTING

The design of a motor's windings and the pattern of connecting the leads from these windings will determine voltage ratios for dual-voltage motors and may also determine what starting options are available.

Following is a brief description of some of the more popular starting methods:

1. Full Voltage Starting

This method is the least expensive from an initial cost standpoint and is the most commonly used starting method on smaller motors. While it results in the highest inrush current values, connections and starter operation are greatly simplified. All standard motors are designed for full voltage (across-the-line)



End User:

Application Information (e.g. fan, pump, crusher):

Type of Driven Load (e.g. variable torque, constant torque, constant horsepower):

Motor Rating - Required

Horsepower:

Frame size:

Speed:

Motor Enclosure:

Voltage:

Shaft Orientation (e.g. horizontal, vertical shaft up, vertical shaft down):

Belt Information - Required

Distance between face of motor endshield and center line of motor sheave width (L):

Inertia of driven load referred to the motor shaft (lb - ft²) (Required for centrifuge):

The following is not required when a Load Analysis Data Output Sheet is provided:

Option A

Motor sheave pitch diameter (Dm):

Driven sheave pitch diameter (Df):

Center-to-center distance between sheaves (C-C):

Motor height vs. driven shaft (H):

Width of motor sheave (W):

Weight of motor sheave (lbs):

Belt service factor:

Belt Type (e.g. 5V, 3VX):

Number of belts:

Option B

Radial Load/Belt Pull (lbs):

This page must be completed for:

- a) 720 rpm and slower motors (10 or more poles)
- b) 447T and larger frame sizes
- c) Non-standard L10 values
- d) Customer requests

starting.

2. Part Winding Starting (PWS)

This method energizes only part of the total winding when the motor is started and is suitable for pump, fan and compressor loads. PWS will reduce inrush current, but the motor heating rate will increase considerably. There are no standard performance requirements for part winding starting and, therefore, a motor started in this manner may fail to accelerate a high-inertia or constant torque load. PWS usually requires special winding connections which must be specified at the time the motor is ordered.

3. Autotransformer Starting

In contrast to part winding start, autotransformer starting uses the complete motor winding but limits input voltage to reduce inrush current.

The most commonly furnished taps on autotransformer

starters are 50, 65 and 80% of full voltage, and most also provide an adjustable timer for switching to full voltage after the motor has accelerated. No special motor winding is required.

Table 16. Autotransformer Starter

Transformer Tap	% Full-Load Value		
	Voltage & Current at Motor	Supply Line Current	Motor Output Torque
80% Tap	80	64*	64
65% Tap	65	42*	42
50% Tap	50	25*	25

* Autotransformer magnetizing current not included. Magnetizing current is usually less than 25 percent of motor full-load current.

4. Wye Start/Delta Run

This connection method allows a motor to be started at reduced load with reduced phase voltage and, therefore, with reduced inrush current. Wye Delta starters may be furnished with either open or closed transitions. Open transition, while generally lower in cost, will produce higher transient current than a closed transition starter at the transition from wye to delta.

MECHANICAL CONSTRUCTION

ENCLOSURE MATERIAL

Frame and endshield materials are listed below in Table 17.

Table 17.

Frame Size	Enclosure	Frame & Endshield Material
182-449	DP, TEFC, WPI	Aluminum alloy, cast iron or rolled steel
509-5013	DP, TEFC, WPI, WPII	Cast iron
182-449	Severe-duty	Cast iron
182-5013	Explosion-proof	Cast iron
182-286	DP, TEFC, WPI	Roller steel or cast iron
324-5013	DP, TEFC, WPI, WPII	Cast iron
182-5013	Severe-duty	Cast iron
182-5011	Explosion-proof	Cast iron

DRAINS AND BREATHERS

ENCLOSED MOTORS (EXCEPT EXPLOSION-PROOF)

Standard enclosed motor construction includes drain holes in the bottom of the motor. On XSD severe-duty motors, special plugs designed to serve as both drains and breathers are inserted into the drain holes. Available as an option is a sintered-metal breather and drain which acts as a one-way vent preventing entrance of contaminants while allowing the moisture to drain out.

EXPLOSION-PROOF

Standard explosion-proof motors are furnished without drains or breathers. Available as an option is the UL listed Crouse-Hinds breather/drain which acts as a one-way vent, preventing the entrance of contaminants while allowing moisture to drain out of the motor.

MOUNTING CONFIGURATIONS

The following diagram illustrates the various mounting possibilities for "horizontal" motors.

Enclosed motors may be furnished for any of the twelve mounting configurations shown in Figure 23. 182-286 frame dripproof motors may be furnished for F1 and F2 mounting only. 324-449 frame dripproof motors may be furnished for any of the twelve mounting configurations.

Unless otherwise specified, all horizontal motors will be furnished for F1 mounting.

VERTICAL MOUNTING

Ball bearing motors in frames 326 and smaller mounted

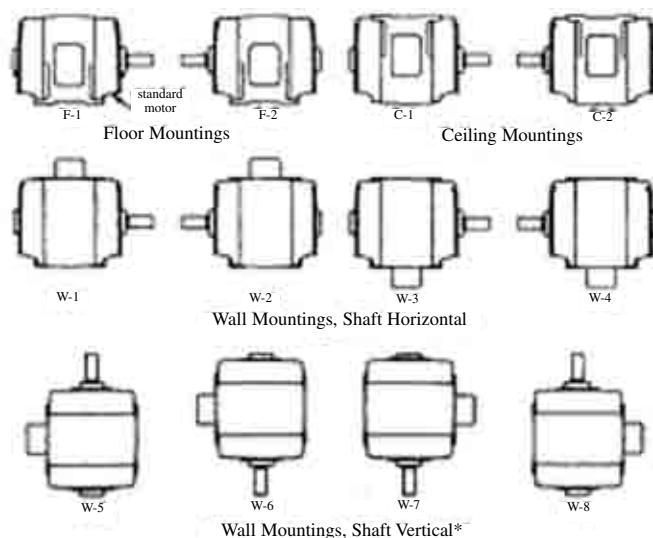


Figure 23.

vertically with shaft up or down can handle external thrust loads, in either direction, not exceeding the thrust value shown in Table 14. Larger motors require a special lubrication system which can be furnished on request. Motors which are to be mounted vertically must be specified shaft up or down to obtain a suitable bearing and lubrication system.

DYNAMIC BALANCE

General Electric motors are dynamically balanced so that vibration, as tested per NEMA standard MG-1-12.08, will be within the limits stated below for standard balance. Motors balanced to either the special or precision balance limits shown will be furnished at additional price when specified. Precision balance is a feature of the XSD severe-duty product line.

Table 18. Vibration Limits (182-5013 Frame)

Motors with two ball bearings Vibration measured in Inches/Sec.			
RPM	Standard	Special	Precision
All speeds	0.15	0.075	0.055
Motors with one ball bearing and one roller bearing Vibration measured in Inches			
RPM	Standard	Special	Precision
3000-4000	0.0010	0.0005	0.0003
1500-2999	0.0015	0.0008	0.0004
1000-1499	0.0020	0.0010	0.0005
999 and slower	0.0025	0.0013	0.0007

BEARING SYSTEMS

ANTI-FRICTION

All standard motors are equipped with "clean steel" Conrad deep-groove-type ball bearings, sized for the loads to be expected in industrial applications.

SLEEVE-TYPE

Split-sleeve bearings are available for frames 509 through 5013 in dripproof and Weather Protected I and II enclosures. They should be used for direct drive applications only.

These bearings are mounted in the bottom and top halves of the split endshields. The top half endshield is removable for bearing or winding inspection.

Solid sleeve bearings are available for frames 509 through 5013 totally enclosed fan-cooled machines. Sleeve bearings are not available on explosion-proof motors.

All sleeve bearings are equipped with oil reservoirs, ring oilers, sight gauges, level gauges and drain provisions.

BEARING LUBRICATION

Ball bearing motors are shipped with sufficient grease for a long operating period. Relubrication at intervals consistent with the type of service shown in the following table will provide longer bearing life.

Excessive, too frequent lubrication or the use of noncompatible lubrication may damage the motor. Follow relubrication type and use procedures provided in the instructions shipped with motors.

Table 19. Relubrication Intervals

Type of Service	Typical Examples	Hp Range	Relubrication Interval (yrs)	
			Horizontal	Vertical
Easy	Valves, door openers, portable floor sanders, motor operating infrequently (one hour per day)	1.0-7.5	10	9
		10-40	7	3
		50-150	4	1.5
		200-350	3	9 Mo.
		400-800	1	—
Standard	Machine tools, air-conditioning apparatus, conveyors, one or two shifts, garage compressors, refrigeration machinery, laundry machinery, oil well pumps, water pumps, wood working machinery.	1.0-7.5	7	3
		10-40	4	1
		50-150	1.5	9 Mo.
		200-350	1	3 Mo.
		400-800	9 Mo.	—
Severe	Motor for fans, M-G sets, etc. that run 24 hours per day, 305 days per year, coal and mining machinery, motors subject to severe vibration, steel mill machinery.	1.0-7.5	4	1.5
		10-40	1.5	9 Mo.
		50-150	9 Mo.	3 Mo.
		200-350	9 Mo.	1.5 Mo.
		400-800	3 Mo.	—
Very Severe	Dirty, vibrating applications, where end of shaft is hot (pumps and fans), high ambient temperatures	1.0-7.5	9 Mo.	9 Mo.
		10-40	4 Mo.	3 Mo.
		50-150	4 Mo.	2 Mo.
		200-350	3 Mo.	1 Mo.
		400-800	2 Mo.	—

ENVIRONMENTAL CONSIDERATIONS

MOTOR ENCLOSURES

The type of enclosure required is dependent upon the surrounding atmosphere in which the motor is installed and the amount of mechanical protection and corrosion resistance required. The two general classes of motor enclosure are open and totally enclosed.

An open machine is one having ventilating openings which permit passage of external air over and around the winding of the motor. A totally-enclosed machine is constructed to prevent the free exchange of air between the inside and outside of the motor, but not sufficiently enclosed to be termed air-tight.

Derivatives of these two basic enclosures are described here.

DRIPPROOF

Dripproof motors are designed to be internally ventilated by ambient air, having ventilation openings constructed so that successful operation is not affected when drops of liquid or solid particles strike the enclosure at any angle from 0 to 15 degrees downward from vertical.

Dripproof motors are typically used in relatively clean, indoor applications.

WEATHER PROTECTED TYPE I (WPI)

A weather protected type I machine is an open machine with its ventilating passages so constructed as to minimize the entrance of rain, snow and airborne particles to the electric parts and having its ventilating openings so constructed as to prevent the passage of a cylindrical rod 3/4-inch in diameter.

WEATHER PROTECTED TYPE II (WPII)

A weather protected type II machine shall have, in addition to the enclosure defined for a weather protected type I machine, ventilating passages at both intake and discharge so arranged that high-velocity air and airborne particles blown into the machine by storms or high winds can be discharged without entering the internal ventilating passages leading directly to the electric parts of the machine itself. For motors in frames 182T through 449T, standard TEFC motors should be specified. Ratings built in frames 509 and larger utilize dripproof frames with "top hat" mechanical construction to meet the above specifications. WPII motors have provisions for air filters.

TOTALLY-ENCLOSED

Totally-enclosed motors are designed so that there is no free exchange of air between the inside and the outside of the enclosure, but not sufficiently enclosed to be airtight. Totally-enclosed motors may be of three basic types of construction.

1. TEFC (Totally-Enclosed Fan-Cooled) This type includes an external fan mounted on the motor shaft. This fan is enclosed in a fan casing which both protects the fan and directs the output air over the motor frame for cooling.

2. TEOA (Totally-Enclosed Air-Over) This type is similar to TEFC designs except that the cooling air being forced over the motor frame is provided by a fan which is not an integral part of the motor.

3. TENV (Totally-Enclosed Non-Ventilated) This type of construction does not require forced airflow over the motor frame for cooling.

4. TEBC (Totally-Enclosed Blower Cooled) is used in applications where a separate mounted blower provides supplementary air to cool the motor. Typical uses are in inverter drive application with low frequency.

PIPED VENTILATION

When motors are cooled by piping in outside air, the required airflow in cubic feet per minute (CFM) can be calculated from the equation:

$$CFM = \frac{Hp \left(\frac{100}{Eff_{\%}} - 1 \right) (746 \times 1.8)}{10}$$

This results in a 10°C air temperature rise.

HAZARDOUS (CLASSIFIED) LOCATIONS

Specially designed totally enclosed motors are available for operation in the classes of hazardous atmospheres, as defined by Underwriters Laboratories, the National Electrical Manufacturers Association and the National Electrical Code. Two basic classes are:

CLASS I EXPLOSION-PROOF

An explosion-proof motor is a totally enclosed machine designed to withstand an explosion of a specified gas or vapor which may occur within it and to prevent the ignition of the specified gas or vapor surrounding the motor.

CLASS II DUST-IGNITION PROOF

A dust-ignition proof motor is a totally enclosed machine constructed in a manner which will exclude ignitable amounts of dust or amounts which might affect performance or rating, and which will not permit arcs, sparks or heat generated inside the enclosure to cause ignition of exterior accumulations or atmospheric suspension of a specific dust and/or in the vicinity of the enclosure.

The various atmospheres defined within the two classes have been divided into groups dependent upon the explosive characteristics of the materials. The class and group of service shall appear on the motor nameplate along with an identification number which identifies a maximum operating temperature as shown in the following tabulations:

Table 20. Hazardous Atmospheres

Class	Group	ID No.	Atmosphere
I	A	T2A	Acetylene
I	B	T2A	Hydrogen, manufactured gas
I	C	T3C	Ethyl ether vapor
I	D	T2A	Gasoline, petroleum, naphtha, alcohols,
		T2D*	acetone, lacquer solvents, natural gas
II	E	T3B	Metal dust
II	F	T3B	Carbon black, coal or coke dust
II	G	T3B	Grain dust

*T2A without thermostat/T2D with thermostat

Table 21. Temperature Identification Numbers

Maximum Temperature Degrees C	Maximum Temperature Degrees F	Identification No.
450	842	T1
300	572	T2
280	536	T2A
200	500	T2B
230	446	T2C
215	419	T2D
200	392	T3
180	356	T3A
165	329	T3B
160	320	T3C
135	275	T4
120	248	T4A
100	212	T5
85	185	T6

NOTE: For motors having multiple UL labels, the lowest identification number will apply.

DIVISIONS, HAZARDOUS LOCATION

The National Electrical Code has defined two distinct divisions within each of the hazardous location classes:

(a) Class I, Division 1 – A Class I, Division 1 location is a location: (1) in which ignitable concentrations of flammable gases or vapors exist under normal operating conditions; or (2) in which ignitable concentrations of such gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or (3) in which breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might also cause simultaneous failure of electric equipment. Division 1 locations always require the use of explosion-proof construction motors.

(b) Class I, Division 2 – A Class I, Division 2 location is a location: (1) in which volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment; or (2) in which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilating equipment; or (3) that is adjacent to a Class I, Division 1 location, and to which ignitable concentrations of gases or vapors might occasionally be communicated. The National Electrical Code allows the installation of non-explosion-proof motors in Division 2 locations.

(c) Class II, Division 1 – A Class II, Division 1 location is a location: (1) in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures; or (2) where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through simultaneous failure of electric equipment, operation of protection devices, or from other causes; or (3) in which combustible dusts of an electrically conductive nature may be present. Division 1 locations always require the application of the appropriate dust-ignition proof motor.

(d) Class II, Division 2 – A Class II, Division 2 location is a location: (1) in which combustible dust will not normally be in suspension in the air in quantities sufficient to produce explosive or ignitable mixtures, and dust accumulations are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus, or (2) dust may be in suspension in the air as a result of infrequent malfunctioning of handling or processing equipment, and dust accumulations resulting therefrom may be ignitable by abnormal operation or failure of electrical equipment or other apparatus. The National Electrical Code specifies Class II, Division 2 motors have no external openings and comply with external surface temperature limits when operating at full-load in free air. The surface temperature limits vary with dust characteristics such as ignition temperature, susceptibility to dehydration and potential for carbonization. The controlling document is ANSI/NFPA 70; material characteristics are detailed in NFPA 497M.

CAUTION: THE RESPONSIBILITY OF SPECIFYING THE PROPER CLASS, GROUP AND DIVISION OF HAZARDOUS LOCATION RESIDES WITH THE ULTIMATE USER AND THE INVOLVED REGULATORY AGENCY.

SPECIAL WINDING TREATMENT

Various winding treatment options and protective coatings are available to provide additional protection in special or extreme application and environmental conditions.

ENCAPSULATED WINDING (FRAMES 440-5013)

Additional protection against moisture is provided by an encapsulated winding. These motors meet NEMA MG-1-1.27.1. Totally enclosed construction is suggested for motors in frames 286 and smaller.

CUSTOM POLYSEAL MOTORS (FRAMES 400-5013)

These motors are available with vacuum pressure impregnated windings which have been taped to hold additional varnish and to increase their mechanical strength. Custom Polyseal motors meet NEMA MG-1-1.27.2 and are capable of an underwater submergence test which includes a hipot and megger test.

ABRASION RESISTANCE (320-5013)

These motors can be supplied with an abrasion resistant winding treatment which gives added protection from airborne particles.

MODEL NUMBER NOMENCLATURE

The following nomenclature is the basis for the majority of GE integral-hp motor model numbers. The model number format shown below provides basic descriptive information as follows:

Model:	<u>5</u>	<u>K</u>	<u>215</u>	<u>A</u>	<u>L</u>	<u>205</u>	<u>A</u>	<u>E</u>
Description:	1	2	3	4	5	6	7	8

1. The numeral "5" is used to designate rotating electrical machinery

2. Electrical Type Letters

a. Polyphase:

- K NEMA designs A & B
- KAF Adjustable frequency
- KE NEMA design A & B complying with Federal Energy Act
- KG NEMA design C
- KGS NEMA design C Energy Saver
- KL Hydraulic elevator
- KOF Oil well pumping
- KR NEMA design D
- KS NEMA design A & B Energy Saver
- KY Special characteristics

b. Single-Phase:

- KC Capacitor start
- KCJ Capacitor start high torque
- KCY Special capacitor start

3. NEMA frame size

4. First form letter

a. Group 1. The following take precedence over all Group 2 letters (except explosion-proof)

- M Marine motors
- N Navy motors
- P Partial motors
- T Textile motors
- S Severe-duty motors

b. Group 2. Are shown in Table 22.

Table 22.

Type	DP	TEFC	TENV or TEAO	Explosion-Proof	WPI
Footed frame and no custom mounting rabbots or auxiliary devices such as brakes	A	B	H	C	E
Round frame and no auxiliary devices such as brakes	D	F	W	G	-
All others	J	K	K	R	-

5. Second form letter

- C Cast iron construction (sourced)
- D Rolled steel, 182-286 frame
- E Cast iron, 182-286 frame
- L Aluminum horizontal (obsolete)
- N Cast iron construction horizontal
- P Aluminum alloy vertical (obsolete)
- S Cast iron horizontal, 320-449 frame
- T Cast iron vertical P-base

6. Form numbers

a. Number of Poles. For horizontal motors, the first digit in the series represents the number of poles divided by 2:

1 = 2 pole

2 = 4 pole

etc.

The number "9" is reserved for multispeed.

b. Nameplate Voltage. The last digit in this series designates input voltage for stock horizontal motors only.

4 = 575 volts

5 = 230/460 volts

6 = 200 volts

8 = 460 volts

7. First suffix letter

Denotes interchangeable design change of the complete motor. If the first suffix letter is present it will be A, B, C, D, D1, D2... or D99.

8. Second suffix letter

Denotes special item or thermal device

a. Special items

F2, W1, W2, W3, W4, W5, W6, W7, W8, C1, C2

b. Thermal devices

S, T, X = Klaxon automatic reset

U, W, Y = Klaxon manual reset

M = Sensor, thermistor, or RTD

P = Thermostat

ELECTRICAL MODIFICATIONS**CURRENT TRANSFORMER**

It is sometimes desirable on larger motors to have current transformers installed in the motor conduit box for operation of auxiliary devices or sensing circuits. Motors in frames 509-5013 can be furnished with single-secondary current transformers in

the main or neutral leads. These can include window-type transformers or bar-type transformers to meet the specifications of the user or the control manufacturer and must be fully specified by the customer. Current transformers require an oversize conduit box which must be included in the order.

GROUNDING PROVISIONS

Special grounding provisions can be supplied in the conduit box for mounting in the drive end endshield.

The special conduit box grounding provision consists of a brass stud in place of one of the conduit box mounting screws. Also included are two jam nuts for mounting to an external ground lead.

Hardware for the endshield grounding option is shipped as a kit including a brass stud, nut and washer. The stud is assembled in place of one of the endshield bolts.

LEADS, SPECIAL

All motors are provided with standard leads of ample length for easy connection in the conduit box to the power leads. Lead size and material are dependent upon the class of insulation system in the motor and the current capacity required. Longer than standard leads are available.

STARTING CURRENT, LOWER THAN STANDARD

The starting current code (KVA-per-horsepower) for polyphase 60 Hz motors in the integral-hp sizes is code G. Reducing the amount of starting current to code F limits or lower may require more material, increased frame size or a combination of these factors. Starting torque and breakdown torque may also be reduced to less than NEMA design B limits.

SURGE PROTECTION

Surge protection capacitors and lightning arrestors can be supplied on 500 frame motors as a package in an oversize conduit box for mounting adjacent to the motor.

TEMPERATURE RISE, SPECIAL

NEMA has defined allowable winding temperature rise according to class of insulation and maximum ambient temperature. Where there are requirements for special low winding temperature rise, please contact the company for review of the available options.

TERMINALS, SPECIAL

All motors with AWG #12 or larger leads are supplied with "AMP" ring terminals similar to Figure 24. "Burdndy Hydenty" terminals can be supplied on motors in frames 284 and larger on request.



Figure 24. AMP Ring Terminal

Motors with AWG #14 or smaller leads will be supplied with lead wire stripped for connection to power leads.

THERMAL PROTECTION

The following devices are applicable only to motors with class B or F insulation.

Built-in protective devices to prevent motor overheating may be either: (A) Line interrupting devices which open the power supply when the motor overheats or (B) pilot devices. The latter open the holding coil circuits of a magnetic switch to take the motor off of the line, or energize alarm bells or warning lights. Motors taken off line by pilot devices typically cannot be restarted until an operator recloses the magnetic starting switch.

A. Line-Interrupting Devices – Current-Sensing Thermal Protectors

These protectors sense both motor temperature and current and offer inherent protection against all abnormal stalled and running conditions. They are built into the motor conduit box for automatic* reset operation on three-phase dripproof motors 182-184 frames and for both automatic* and manual reset operation on single-phase motors 182-215 frame.

These protectors are not available on explosion-proof motors or on two-winding multispeed motors.

***WARNING: A MOTOR WITH AUTOMATIC-RESET THERMAL PROTECTION SHOULD NEVER BE USED WHERE AN UNEXPECTED RESTART MAY INJURE PERSONNEL OR DAMAGE PROPERTY.**

B. Pilot Devices

(1) Thermostats

Thermostats are mounted on the stator winding and are temperature-sensing only. They are available with normally open or normally closed contacts and only for automatic reset.

Thermostats will protect the motor from high ambient temperature, exceedingly long accelerating cycles (where the design is not rotor limited), repeated or excessive overloads and loss of ventilation. However, they do not give protection under stalled or locked-rotor conditions and must be used with an external current-sensitive motor control for complete motor protection.

Thermostats can be installed in all motor enclosures. They are not recommended for machines with nameplate voltages exceeding 600 volts.

Thermostats are suitable for the following pilot circuits:

Table 23.

Power Supply	Voltage	Current
AC	110-115 volts	0.0 amp
AC	220-230 volts	3.0 amp
AC	440-480 volts	1.5 amp
AC	550 volts	1.2 amp
DC	115-125 volts	2.2 amp
DC	230-250 volts	1.1 amp
DC	550 volts	0.4 amp

(2) Thermistors

Thermistors are small non-linear resistance devices placed in the stator windings. As the critical temperature is reached, the resistance of the thermistors changes radically, causing operation of a control relay. Normally, 3 thermistors are

furnished, one per phase. Thermistors may be furnished with or without a separate (greater than 600 nameplate volts) control relay. Thermistors are not recommended on high voltage encapsulated or Custom Polyseal machines.

(3) Resistance Temperature Detectors

RTDs are precision wire-wound resistors with calibrated temperature-resistance characteristics. These devices are used in conjunction with customer supplied instruments and are available in 10, 100 and 120 ohm designs. Normally six RTDs (2 per phase) are furnished per motor, suitably distributed around the circumference of the stator winding, located between coil sides and positioned to detect the highest slot temperature.

MECHANICAL MODIFICATIONS

BEARINGS – THERMAL PROTECTION

Bearing thermal protection is available on 509-5013 frame motors and is most practical for sleeve bearing machines. Bearing temperature relays or temperature detectors can be provided to either operate an alarm system or indicate temperature levels. The customer must specify the type of system required and whether temperature indicators are to be furnished by General Electric.

BRAKES

Brakes supplied mounted on motors will be disc-type, spring set electrically released brakes manufactured by either Stearns Electric Corp. or by Dings Brakes, Inc. at General Electric Company option. Brakes are available for motors in frames 182- 326 only.

Several factors must be considered when determining the correct brake for a particular application.

Brakes provided on the motors are available on NEMA frame 140 through 320. Larger frame sizes must be used when floor brakes are mounted separately.

1. Brake Torque

As a general rule of thumb, the torque rating of a brake should, as a minimum, match the full-load torque of the motor on which it is mounted. This will provide ample torque if the brake is used for holding and will also provide a stop in approximately the same time as required for acceleration. Full-load torque can be calculated as follows:

$$\text{Full-Load Torque} = \frac{5252 \times \text{Hp}}{\text{Full-Load Speed}}$$

For applications involving high inertia load, fast stops or a stop within a given time limit, the brake should be selected on the basis of total inertia to be retarded. Brake rating may be calculated as follows:

$$\text{Torque} = \frac{\text{WK}^2 \times \text{RPM}}{308 \times t}$$

Where: WK^2 = Load Inertia in lb-ft²
 RPM = Full-Load Speed in RPM
 t = Time, in seconds, to stop

Standard brake torque ratings or continuous duty include: 6, 10, 15, 25, 35, 50, 75, 105, 125, 175, 230, 330, 440, 550 lb-ft. If the calculated brake torque falls between the standard torque values, specify the next higher torque.

2. Brake Voltage

Brakes are supplied for operation on the same voltage as the motor unless otherwise specified. In the case of dual voltage motors, brake voltage will be the lower of the motor voltages, unless otherwise specified. Standard brake voltages are:

60 hertz 200, 230, 460, 575 Volts

50 hertz 200, 220, 380, 415, 440, 550 Volts

Stearns brakes are all single-phase. Dings brakes are single-phase up to 9 lb-ft and three-phase in larger ratings.

Brake leads are terminated at a conduit connection on the brake.

3. Brake Enclosure

Brakes are available in enclosures to match the needs of the environment in which they will be operating. Standard enclosure is for application on drip-proof or totally-enclosed fan-cooled motors for indoor or semi-protected outdoor installations. Dusttight, waterproof enclosure is suitable for severe-duty and totally enclosed motors used in conditions of extreme moisture, abrasive or conductive dusts, acid or alkali fumes or for outdoor installation.

4. Vertical Mounting Position

Brakes must be specially modified for vertical mounting. Specify if the motor will be above or below the brake.

CONDUIT BOX, SPECIAL

Standard conduit boxes meet or exceed NEMA and NEC volumes and are adequate for connecting all necessary leads for power and any incidental control circuits.

Available options for motors in frames 182 through 449 include extra 3/4 inch conduit hole for drip-proof TENV and TEFC motors, additional conduit box, waterproof conduit box and oversize box.

Motors in frames 509-5013 are available with a 2500 cubic inch motor mounted box suitable for stress cone connections or for mounting accessory equipment. This special box is furnished as standard for all motors of 3000 volts and above. Three stand-off insulator-supported copper bar terminations for motor leads can be furnished if specified. An 11,000 and a 17,000 cubic inch motor mounted conduit box are available. In addition, a 44,000 cubic inch floor mounted, conduit box is available to mount beside the motor with conduit connection to the motor frame. This construction allows the customer to mount accessories such as current transformers, surge capacitors, lightning arrestors, etc.

COUPLINGS

Motors are normally furnished without couplings; however, a one-piece half coupling can be installed on the motor shaft at the factory providing it is balanced, finished machined and key-seated to motor shaft dimensions. It must be shipped prepaid to the factory of motor manufacture before the start of production. Motors are dynamically balanced prior to installing the half coupling and are not rebalanced after coupling assembly.

A vibration test with half-coupling installed will be performed and a test report issued when this special service is

requested by the customer and included in the quotation.

DOWEL HOLES IN FEET

Dowel holes are furnished as standard on 500 frame motors as an alignment aid. One 1/2 inch hole is provided in each of the diagonally opposite feet.

ENDSHIELDS, SPECIAL

Horizontal motors are available with Type C face, and D flange endshields, which have rabbets and bolt holes for mounting equipment to the motor, or for overhanging the motor on a driven machine.

The Type C face endshield provides a male rabbet and tapped holes for mounting bolts. This endshield is used for mounting small apparatus, such as pumps, to the motor. The Type D flange has a male rabbet, with holes in the flange for through bolts. This flange is primarily used on machine-tool gear boxes.

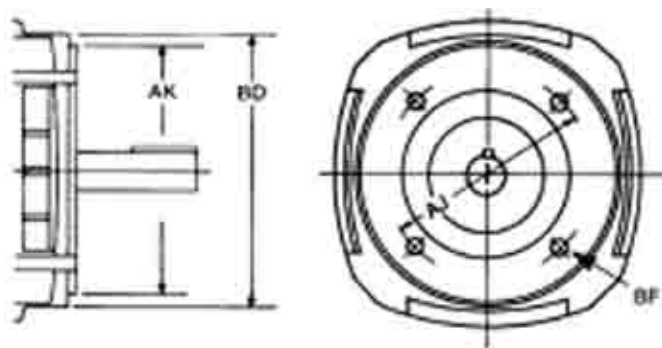


Figure 25. Type C-Face

Table 24. C-Face Mounting Dimensions (inches)

Frame Size	Face Diameter	Rabbit Diameter	Bolt Circle	Bolt Holes	
	BD	AK	AJ	BF	
Dimensions in inches					
182-184	8.50	8.50	7.25	.50-13	.75
213-215	8.68	8.50	7.25	.50-13	.88
254-256	8.68	8.50	7.25	.50-13	.88
284-286	10.75	10.50	9.00	.50-13	.88
324-326	12.75	12.50	11.00	.625-11	1.00
364-365	13.00	12.50	11.00	.625-11	1.00
404-405	13.00	12.50	11.00	.625-11	1.00
444-449	17.50	16.00	14.00	.625-11	1.00

Note: Frame 182 through 326 have 4 holes; 364 and larger have 8 holes

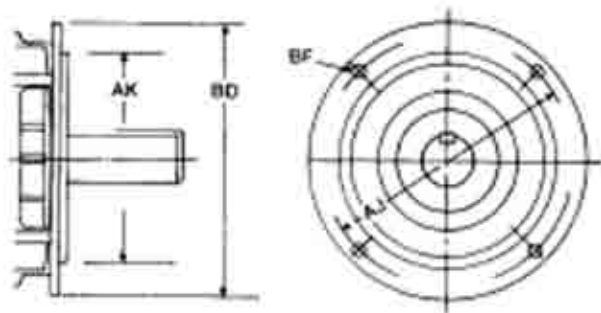


Figure 26. Type D-Flange

Table 25. D Flange Mounting Dimensions

Frame Size	Flange Diameter	Rabbit Diameter	Bolt Circle	Bolt Holes
	BD	AK	AJ	BF
Dimensions in inches				
182-184	11.00	9.00	10.00	.53
213-215	11.00	9.00	10.00	.53
254-256	14.00	11.00	12.50	.81
284-286	14.00	11.00	12.50	.81
324-326	18.00	14.00	16.00	.81
364-365	18.00	14.00	16.00	.81
404-405	21.90	18.00	20.00	.81
444-449	21.94	18.00	20.00	.81

NOTE: Frames 182 through 365 have 4 holes. 404 and larger have 8 holes.

C-face and D-flange kits are available for field modification of standard motors by an Authorized GE ServiCenter. These kits are provided as a convenience item. Conventional motors will not meet NEMA BE dimensions and there is some loss in usable shaft length.

FRAME, NON-STANDARD

Requests are occasionally received to furnish motors in frame sizes either larger or smaller than NEMA standard. If frame size larger than standard is to be supplied, the standard motor rating for that frame size will be furnished. If smaller than standard frame is required, please contact the Company for feasibility and terms.

GREASE & RELIEF FITTINGS

Motors with regreaseable bearing systems can be supplied with regrease fittings and automatic grease relief devices. Severe-duty motors are supplied with extended hydraulic grease fittings and plugs.

SHAFTS, SPECIAL

Motors are furnished with a single straight shaft with sled runner keyway and a rectangular key. For motors in frames 182 through 449, a long shaft for V-belt drive is supplied for a majority of ratings and is denoted by the suffix "T" or "L" on the motor frame size. Two-pole (3600 RPM) motors in frames 284 through 449 and certain other 449 frame ratings are furnished with short shafts for direct connection.

These motors are denoted with the suffix "TS", "LL" or "LS" on the motor frame size. Standard double-end shaft extensions are available for motors in frames 182 through 5011.

Special shaft designs are available including differences in dimensions and/or materials as follows:

- Length: Up to 10 inches longer than standard for motors in frames 182-449. Up to 13 inches longer than standard for motors in frames 509-5013. Longer than standard shafts are usually suitable for direct connection. Other drives such as belts or gearing may require special bearings and should be referred to Company.
- Keyway: Sled-runner, round end, or Woodruff #3 or #9
- Hole: Drilled radially or in the end of the shaft. Drilled and tapped in the end of the shaft. Hole depth limited to three times the hole diameter 26.

- Steps: One or more reductions in shaft diameter.
 Threads: Class 2A right-hand thread of size appropriate to the shaft diameter.
 Squared: Milled flats on four sides of one step.
 Tapered: 1 1/4 or 1 1/2 inch per foot taper with threads, nut and lock washer.

ENVIRONMENTAL MODIFICATIONS

Care is needed in using motors that have a combination of unusual environmental conditions. For example, a motor with a requirement of high altitude plus high temperature and service factor may be available only in an oversized frame.

ALTITUDE

The rating of standard motors assumes operation at sea level in a 40°C ambient. For purposes of standardization it is considered that there is no difference in motor operating temperature between sea level and 3300 feet altitude.

The cooling effect of ventilating air is a function of its density. The atmospheric pressure and density at higher altitudes is reduced and the air cannot remove as much motor heat, causing the motor to run hotter. As a general guide, motor temperature rise increases 1% for every 330 feet above 3300 feet. To keep motor heating within safe limits at altitudes above 3300 feet, there are the following alternatives:

A. Supply a motor designed for standard sea level operation which can either be:

(1) Operated at less load (a motor with service factor rating of 1.15 or higher can be operated at altitudes up to 9000 feet with a 1.0 service factor), or

(2) Operated in a lower ambient temperature per the following table:

Table 26.

If Ambient Temperature is:	Maximum Altitude with Same Service Factor is:
30°C	8000 ft
20°C	9900 ft

It should be remembered that, although the outdoor ambient temperature at higher altitudes is low, motors probably will be installed indoors in higher ambient temperatures.

Motors applied per A(1) or A(2) above, will have no special altitude or temperature data on the nameplate.

B. Supply a special motor designed for the required high altitude operation, with appropriate data stamped on the nameplate.

HIGH AMBIENT, POLYPHASE

Standard motors are designed so that the temperature rise produced within the motor, added to the standard 40°C ambient temperature, will not exceed the winding-insulation temperature limit. If the ambient temperature exceeds 40°C:

A. The temperature rise produced in the motor must be offset by:

(1) Reducing the load and consequent motor losses. A motor rated for a 40°C ambient temperature and operating in a 50°C ambient, will, if rated 1.15 service factor, carry rated Hp with no overload (1.0 SF) and, if rated 1.0 service factor, carry 90% of rated Hp, or by...

(2) Applying a special motor design.

B. The temperature limit may be raised by the substitution of a higher-temperature insulation system, special grease and bearings.

Motors applied per A(1) above will not have special ambient temperature or service factor data on the nameplate.

The choice between A(2) and B rests with the motor designer who also may have to use a frame size larger than is standard for the rating. Explosion-proof motors may require frame sizes different from the corresponding totally enclosed motors.

WARNING: THE MAXIMUM ALLOWABLE AMBIENT TEMPERATURE FOR EXPLOSION-PROOF MACHINES IS 60°C.

HIGH AMBIENT, SINGLE-PHASE

For operation in ambient temperatures higher than 40°C, refer to Company giving full details of the application.

LOW AMBIENT

For operation in ambient temperatures of less than minus 40°C, give full details of the application. Special low-temperature grease and special steel shafts may be required.

DRIP COVERS (WALL OR VERTICAL MOUNTING)

Drip covers can be furnished on standard horizontal motors for added protection from dripping liquids and falling objects when the motor is mounted in other than the normal horizontal position.

If dripping liquids are present in the application, protective covers are recommended for dripproof construction motors mounted shaft up or shaft down.

EXPORT BOXING AND PACKING

Export boxing and packing should be specified when a motor, and/ or spare parts, are to be furnished for export shipment.

GREASE, SPECIAL

Motors designed for unusual environmental conditions or special duty should have bearing grease selected for such service. The most commonly encountered conditions requiring special lubricants are extremely high or low operating ambients. The majority of motor greases used by GE are suitable for operation at ambient temperatures from minus 40°C to plus 40°C.

HARDWARE

Standard motor hardware has a plated protective coating suitable for the corrosive atmospheres generally encountered. For extremely corrosive atmospheres, stainless hardware may be required, and should be specified.

PAINT

STANDARD FINISHES

Motors are protected by a two-coat paint system. The first coat is a rust-inhibitive primer applied to protect the castings during storage and manufacture. The second coat is a medium light gray or buff semigloss paint.

Most commercially available paints are compatible with the paint system described above. It is recommended that the customer apply any finish coat over the motor paint in his plant when the driven equipment is painted.

SCREENS**Intake and Discharge Screens – Dripproof Guarded**

Corrosion resistant screens can be furnished over the air-intake and discharge openings of dripproof motors. Dripproof motors equipped with these screens conform to the “Dripproof Guarded” definition appearing in NEMA MG-1, Part 1.

Rodent Screens – Rodent screens will be provided where required as part of the dripproof guarded system and on specific request of the purchaser.

SEALS, SHAFT

The following tabulation lists the sealing arrangement where shafts emerge from the motor bearing housings.

Table 27. Shaft Seals

Motor Enclosure	Motor Frame	
	182 449	508 5011
	Shaft Seal	
Standard Dripproof	F	F
Enclosed	F	F
Severe-duty Enclosed	S	S
Explosion-proof	F*	F*

F = Close running fit at both ends.

S = Neoprene slinger steel reinforced DE only.

* Except Class I, Group E motors which have non-sparking labyrinth seals.

SPECIAL AND DEFINITE PURPOSE APPLICATIONS**CLOSE-COUPLED PUMP MOTORS****DESCRIPTION:**

These motors are designed to meet the requirements of motor mounted centrifugal pumps.

Product Line:

NEMA Design	B (GE Types K and KC)
Enclosure	Dripproof or Totally-Enclosed Fan Cooled
Frames	182-365
Voltage	200, 230, 460, 575
Frequency and Phase	60 hertz, 3-phase or single-phase
Ambient	40°C Dripproof, 1.15 Service Factor 40°C TEFC, 1.15 Service Factor
Ratings	1 through 60 Horsepower
Standard Features:	

Motors feature a NEMA Type C-face endshield and a standardized shaft extension on which the pump casing and impeller are mounted.

Machining is to close axial and radial tolerances. Motor dimensions for this compact assembly are per the NEMA “JM” and “JP” standards established in conjunction with the pump industry. Standardization permits a high degree of interchangeability of pump and motor sizes; special pump parts are held to a minimum.

ENERGY SAVER EXTRA SEVERE-DUTY MOTORS**DESCRIPTION:**

The X\$D line of premium efficiency motors is designed especially to operate in the rugged environments found in the process industries such as chemical, petroleum, plastic, paper,

metals and cement. These Extra Severe-Duty motors are well suited for a wide variety of applications including pumps, compressors, fans, blowers, materials handling equipment and drives for special process machinery – wherever premium efficiency, reliability and long life are basic requirements of the application.

PRODUCT LINE:

NEMA Design	B and C (GE Types KS and KGS)
Enclosure	TEFC Extra Severe-Duty Explosion-Proof, Extra Severe-Duty
Frames	182-449
Voltage	230, 460 or 575 Volts
Frequency and Phase	60 hertz, 3-phase
Ambient	40°C, 1.15 Service Factor
Ratings Available	3-250 Hp, 3600 RPM 3-250 Hp, 1800 RPM 1.5-200 Hp, 1200 RPM 1-150 Hp, 900 RPM

XSD FEATURES:

As a result of careful reviewing of the special needs of the process industries, motors in this product line include many unique features. X\$D motors have a bearing life (L10a) of 50,000 hours for belted applications.

All X\$D motors have bearing life (L10a) of 50,000 hours. Lower motor temperature provides a cooler operating bearing system which significantly increases grease life. The combination of the better bearings and long life grease improves motor reliability and reduces maintenance costs. Motors are equipped with regreasable antifriction bearings with readily accessible inlet hydraulic grease fittings and Allen head outlet plugs for convenient relubrication.

Motors are dual-rated with a service factor of 1.15 in a 40°C ambient or 1.0 in a 65°C ambient. Premium efficiency provides extra thermal margin, often allowing these motors to be used on adjustable speed drives without derating. The extra margin also provides protection against momentary conditions of overloads, voltage fluctuations, single-phasing and stall. Thermal margin can be utilized to meet the needs of duty cycle loads. X\$D motors are available with NEMA design B (normal) or NEMA design C (high) starting torque.

Cast iron frame and endshield construction is used for these totally enclosed fan-cooled motors. All external parts are protected by epoxy paint or equivalent. The stainless steel motor nameplate provides complete motor data including efficiency values and bearing numbers. All hardware is corrosion resistant.

The conduit box gasket is fully gasketed with a nipple lead gasket between the box and motor frame and another between the cover and box. Further protection of internal parts is provided by an external slinger on the motor shaft which helps prevent moisture from seeping along the shaft into the motor.

Motors are built with a full class F insulation system using non-hygroscopic materials throughout to resist moisture and help extend thermal endurance. Air gap surfaces are protected against corrosion.

Safety features include a grounding stud in the conduit box plus built-in lifting lugs for easy installation and maintenance. All X\$D motors have CSA approval.

MULTISPEED MOTORS**DESCRIPTION:**

Multispeed motors are applied where operation at two, three or four definite speeds is desired. The motors are classified as to the relation of full-load torques at rated speeds: i.e., constant torque, variable torque and constant horsepower.

PRODUCT LINE:

NEMA Design	NEMA design does not apply for multispeed motors (GE Types K, KS)
Enclosure	Dripproof or Totally-Enclosed, Explosion-Proof
Frame	Fan-Cooled
Voltage	182-5011
Frequency and Phase	200, 230, 460, 575
Ambient	60 hertz, 3-phase
	40°C, Dripproof, 1.15 Service Factor; 40°C, TEFC, 1.0 Service Factor
Rating	1 through 800 horsepower
	• One winding, two winding • Variable torque, constant torque and constant horsepower • 2 speed, 3 speed, 4 speed

APPLICATION:

Different speeds are obtained by switching electrical connections.

The speed on each connection has the constant speed characteristic typical of single-speed induction motors. Multispeed motors may have a single reconnectable winding or two independent windings.

It is possible to arrange a single winding so that it can be reconnected for a different number of poles (and speed) by suitable reconnection of the leads. However, such an arrangement will permit only two speeds and the speeds must be in the ratio of two-to-one.

An alternate way of securing two speeds is to have two separate windings, each wound for a different number of poles and speed.

Such an arrangement means that one winding is not in use when the other is connected to the line; motor frame sizes usually are larger in order to accommodate the idle winding. But the use of two windings permits two speeds which are not in the ratio of two-to-one. Speeds with a two-to-one ratio can be delivered by two-winding motors as well as by single-winding motors.

The choice between one winding and two winding motors is affected by the speeds desired, the motor price, the control price, wiring complexity and physical size. One winding motors have lower prices than two winding motors but usually require more expensive controls.

A four-speed motor has two windings and each winding is arranged for two speeds having a two-to-one ratio. If one of the two windings is single speed, the motor has a total of three speeds. A motor with three windings, which would permit speed combinations like 1800/1200/720 RPM, is not a practical design.

Multispeed motors are classified by the relation of the full-load torques at the two (or more) full-load speeds.

If the motor has the same full-load torque at both speeds, the motor is a constant torque motor. Since constant torque motors have the same full-load torque at both speeds, the horsepower ratings for the two speeds are in the same ratio as the speeds. For example, the low speed rating of a 10 Hp 1800/900 RPM constant torque motor is 5 Hp.

If the full-load torques are in the same ratio as the speeds, the motor is a variable torque motor. The horsepower at the low speed, involving both reduced torques and reduced speed, compares to the high speed in ratio of the square of the speeds. Therefore, in the case of a 10 Hp 1800/900 RPM variable torque motor, the low speed horsepower is 2 1/2 using the following equation:

$$Hp_{LOW} = Hp_H \left(\frac{RPM_{LOW}}{RPM_H} \right)^2$$

If the full-load torque values at the two speeds vary inversely to the speed, the motor is designated constant horsepower.

The horsepower listing of multispeed motors always applies to the highest speed. The horsepower ratings at the lower speeds are determined by the particular speed and the motor's torque classification.

Motor horsepower is a direct function of both torque and speed.

For each speed of a multispeed motor, the horsepower rating must be equal to, or greater than, the horsepower required by the driven load at each speed.

Constant-torque motors are used on friction type loads, or where the work being done is in direct proportion to the speed. Typical examples of constant torque loads are conveyors, escalators and positive displacement pumps or compressors.

Variable torque motors are normally applied to fans centrifugal blowers and centrifugal pumps which put a horsepower load on the motor which varies as the cube of the speed. If the motor output is adequate for the high speed load, it is sure to have enough Hp at the lower speeds since the motor Hp reduces only as the square of the speed.

Constant horsepower motors are applied on machines that must handle a heavier weight or a greater cut (machine tools) on lower speed than on high speed. For example, a metal-cutting lathe would use the high-speed connection for a light finish cut, but the low-speed connection for taking off large chips in a rough cut.

Multispeed ratings may have lower starting torques than the corresponding single speed ratings.

Multispeed motors are connected in various ways requiring special control, whether manual or magnetic, for starting, changing speeds and stopping. Since the full-load current for high speed is different from that for the lower speeds, separate independent thermal overload relays with correctly selected heaters are required in the control to completely protect the motor on all speed connections.

An alternate is to specify multispeed motors equipped with heat-sensing protectors, built into the winding to positively prevent burnouts caused by overloads, stalling, lack of ventilation, single-phasing or unbalanced voltages regardless of speed, winding connection or ambient temperature.

Multispeed motors are supplied for a single voltage. Motors larger than 365T frame are not furnished for voltages

below 460 volts at 60 hertz (380 volts at 50 hertz).

Multispeed motors may be started on any speed either on full voltage, or on reduced voltage by resistor, reactor or auto-transformer starters. They are not available for wye-delta or part winding starting.

OIL WELL PUMPING MOTORS

DESCRIPTION:

Type KOF motors have special performance characteristics particularly suited to the requirements of beam drives for oil well pumping.

PRODUCT LINE:

NEMA Design Enclosure	D (GE Type KOF) Dripproof Guarded or Totally-Enclosed Fan-Cooled
Frame	213T through 449T
Voltage	460/796 at 1200 RPM; 230/460 at 900
RPM	
Frequency and Phase	60 hz, 3-phase
Ambient	40°C 1.0 Service Factor
Rating	3 through 125 Hp

STANDARD FEATURES:

The construction of the dripproof motors is mechanically strong and resists corrosion. Rodent screens are standard on all ventilating openings.

The motors have a varnish system ideal for rugged outdoor service in the oil fields for the optimum in mechanical protection.

There is a Totally-Enclosed Fan-Cooled motor in all cast iron IP 55 enclosures with a 1.15 service factor.

Electrically, the oil well pumping motor has high slip and high torque to assure lower kw-hr per barrel. Type KOF motors are designed to deliver ideal torque and slip characteristics at the high voltage (460/796 volts) normally available from oil field distribution systems.

TOTALLY ENCLOSED AIR-OVER (TEAO)

DESCRIPTION:

Totally Enclosed Air-Over (TEAO) motors are specifically designed for fan and blower applications where the air being moved passes directly over the motor frame to cool the motor. Motor ratings can be selected based upon velocity of cooling air over the motor frame. It is often possible to select a smaller frame for a given load resulting in cost and space savings. Motor thrust capability ratings assume a fan mounted on the motor shaft. The motors can be belt connected to the fan or blower as long as an adequate velocity of air flows directly over the motor. The totally enclosed construction prevents moisture, dust and other contaminants from entering the motor from the air stream.

Product Line:	
NEMA Design	B (GE Types K, KS)
Enclosure	Totally Enclosed Air-Over
Frames	182-405
Voltage	200, 230, 460 or 575 Standard
Frequency & Phase	60 hertz, 3-phase
Ambient	40°C maximum
Ratings	See Table 29

SELECTION:

The horsepower required by the fan should be determined based on handling "standard" air at 70°F temperature with a density of 0.075 pounds per cubic foot.

Minimum air velocity in feet per minute listed in Table 29 must flow directly over the motor frame for continuous operation at rated horsepower.

The air velocity along the motor is affected by fan design factors such as:

1. Fan hub dimensions relative to motor frame diameter.
2. Fan hub diameter relative to fan blade diameter.
3. Position of the motor in the air stream.
4. Method of mounting motor (feet, face, flange, etc.).
5. Characteristics of air flow (turbulent, laminar, etc.).

In view of these factors and other potential variables, the fan manufacturer has the ultimate responsibility for proper motor selection and applications.

Thrust values in Table 29 assume maximum fan weight and represent the maximum permissible thrust to provide a 14-year average bearing life and a 25,000-hour L10 life in accordance with AFBMA bearing life calculations.

Fan weight shown is the maximum weight of a fan in "commercial balance", concentrated at the end of the motor shaft extension, which is permissible for safe shaft and bearing loading. A fan has commercial balance if its unbalance moment in ounce-inches (the weight in ounces times the distance in inches from the axis of rotation required to produce perfect balance) is numerically equal to, or less than, one percent of the weight in pounds of 1200 RPM and higher speed fans or five percent of the weight in pounds of lower speed fans.

Vertical mounting applications (shaft up or down) should be referred to Company to determine whether drive-end bearing should be clamped.

ADJUSTABLE SPEED INVERTER DUTY OPERATION

PRODUCT

NEMA DESIGN DOES NOT APPLY (GE TYPE KAF)

ENCLOSURE: OPEN DRIPPROOF OR TOTALLY-ENCLOSED

FRAMES: 180-5011

ADJUSTABLE SPEED DRIVE (ASD) OPERATION

Most of today's state-of-the-art inverter drives use IGBT technology. These drives solve the electrical noise problem of the older transistor units but can create significant issues for pre-IGBT motor insulation life. The IGBT drive use frequencies that are above the audible range and can cause significant rapid voltage spikes that may shorten motor insulation life.

Motor manufacturers, through the National Electrical Manufacturers Association (NEMA) technical section have defined IGBT drive output spike voltage as 3.1 times the motor nameplate voltage.

Example: NEMA MG-1-31 states 3.1 times the nameplate voltage or 460 volts X 3.1 = 1425 minimal acceptable voltage spike @ .01 microsecond rise time.

With the use of a more sophisticated design, GE Fuji has solved the spiking issue and offers drive products that keep the spike under 1000 volts and are compatible with older existing motors.

Besides the motor insulation system, the application should consider the shortest leads possible between the drive and motor (50 ft) and make sure the motor has enough thermal

Table 29. Totally-Enclosed Air-Over Motor Application Data

Rated Hp	RPM (Sync)	Frame	Class B Insulation	Max. Thrust Pounds		
			Min Air Velocity (Ft per min) at Rated Hp	Toward Motor	Away From Motor	Max. Fan Wt. (lbs)
1	900	182T	100	235	170	190
1.5	1200	182T	100	210	140	190
	900	184T	150	235	170	190
2	1200	184T	100	210	140	190
	900	213T	200	415	330	250
3	3000	182T	100	130	90	130
	1800	182T	100	160	105+	190
	1200	213T	300	365	280	250
	900	215T	500	415	330	250
5	3000	184T	200	130	90	130
	1800	184T	300	160	105+	190
	1200	215T	150	365	280	250
	900	254T	350	680	470	535
7.5	3000	213T	800	245	185	165
	1800	213T	800	325	230	250
	1200	254T	300	625	395	535
	900	256T	650	680	470	535
10	3000	215T	1500	245	185	165
	1800	215T	1500	325	230	250
	1200	256T	800	625	395	535
	900	264T	300	770	505	690
15	3000	254T	1800	405	345	165
	1800	254T	1100	485	340	420
	1200	264T	800	735	435	690
	900	280T	700	770	505	690
20	3000	256T	2000	405	345	165
	1800	256T	900	485	340	420
	1200	280T	800	735	435	690
	900	324T	800	1005	665	800
25	3000	264T	1500	460	410	165
	1800	264T	1200	610	390	540
	1200	324T	800	975	575	800
	900	326T	800	1005	665	800
30	3000	280T	1500	460	410	165
	1800	280T	1200	610	390	540
	1200	326T	800	975	575	800
	900	364T	900	1330	860	1070
40	3000	324T	1800	625	545	215
	1800	324T	1500	785	455	600
	1200	364T	1000	1235	720	1070
	900	365T	1000	1330	860	1070
50	3000	326T	2000	625	545	215
	1800	326T	1500	785	455	600
	1200	365T	900	1235	720	1070
	900	404T	1000	1670	1060	1200
60	3000	364T	1800	810	670	315
	1800	364T	1700	995	555+	1070
	1200	404T	800	1465	860	1200
	900	405T	800	1670	1060	1200

+Actual L10 = 23,000 hrs.

NOTE: For given thrust, bearing L10 is a minimum of 25,000 hrs.
unless otherwise noted.

most significant are:

Therman stress for low-frequency constant torque loads.
 Low frequency performance - speed oscillation
 Lead length
 System information feedback

If any of these items are necessary or unknown, the user
 should consider the true inverter Duty Motor.

capability to support the application at reduced speeds.

The point here is that being IGBT "Compatible" is not necessarily "Inverter Duty". Standard efficiency motors with appropriate IGBT compatible insulation have as a primary design parameter cost not variable speed loading capability. Many simple applications can be served with these standard motors but all the parameters must be considered. Some of the

DIELECTRIC WITHSTAND TESTING OF MODULAR AND MANUFACTURED HOMES

The Slaughter Company

The controversy of AC vs. DC Dielectric Withstand testing of modular and manufactured homes has been an issue for years, in part due to a misunderstanding of the test itself. Some of the common questions that manufacturers ask are:

- Do I test with AC or DC voltage?
- What is the proper test voltage and what part of the circuit do I need to test?
- How do I interpret my test results?
- How is it possible to be able to test the entire manufactured home with all the appliances still connected without damaging the appliances?

This article addresses these questions and other aspects of AC vs. DC testing.

The U.S. Department of Housing and Urban Development, Manufactured Housing and Standards Division issued a memorandum in June of 2000 to All Primary Inspection Agencies and All State Administrative Agencies regarding dielectric strength testing of modular and manufactured homes as specified in standard # 24 CRF 3280.810(a).

The memorandum states the requirements of the Dielectric Withstand test, which are as follows:

“The wiring of each manufactured home is to be subjected to a dielectric strength test between live parts and the manufactured home ground and between neutral and the manufactured home ground. The test is either to be performed between 900 to 1079 volts for one minute or between 1080 to 1250 volts for one second. The test is conducted on each manufactured home to stress the insulation to determine if it is capable of resisting transient power line surges to which the wiring may become subjected, identify any low resistance areas of the insulating material and any dielectric breakdown paths of failures that may exist.” Please note that the test is not to be conducted from phase to phase, or between the hot and neutral conductors as this could result in damaging appliances that may be connected. The standard does not specify whether AC or DC should be used to perform the test but the voltage ranges indicated in the standards have historically been accepted as AC values.

AC voltages are normally specified as root-mean-square (RMS) values. The RMS voltage is the effective value of a varying or alternating voltage; this value will produce the same power loss as a continuous voltage when applied to a pure resistive load. The peak value of a sine wave is actually 1.414 times greater than the RMS voltage (figure 1). To perform an equivalent DC test, the test potential would be 1.414 times the RMS value to achieve the equivalent peak voltage.

Using the RMS values specified in 24 CRF 3280.810(a) the DC equivalents would be 1273 to 1526 volts for a one minute test or 1527 to 1768 volts for a one second test.

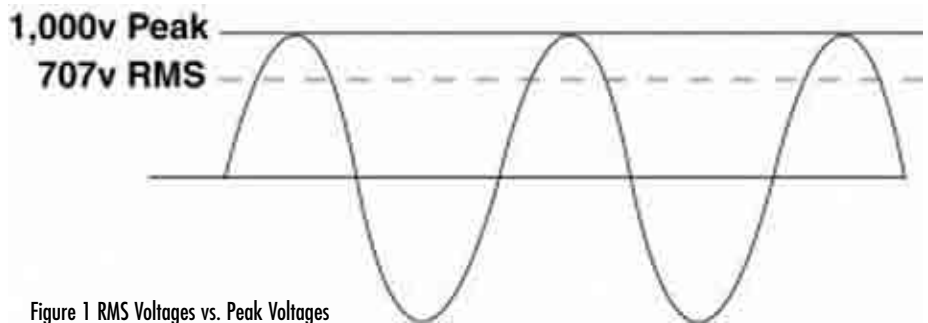


Figure 1 RMS Voltages vs. Peak Voltages

During a hipot test, voltage is applied across the insulating material between current carrying conductors and ground. This, in fact, is very similar to the characteristics of a capacitor, which is simply two conductors separated by an insulating or dielectric material. The circuitry that needs to be tested within a manufactured home can be very capacitive in nature because of the size and surface area of the circuits. For this reason, the majority of the leakage current seen during an AC hipot test can be a direct result of the capacitive reactance of the circuit and not the insulation resistance. This capacitive reactance is low and can range from less than 50k up to 200k ohms in comparison to the insulation resistance of the home, which is typically greater than 1 megohm. A capacitor will allow AC current to flow through it while it blocks the flow of DC current once it charges up to the applied potential. Current flows through a capacitor when there is a change in the applied potential or charge. When performing an AC test, the charge is changing at a rate of 60 cycles per second. This is the reason that AC cannot charge the capacitive component of the device under test (DUT). This results in much higher leakage currents when performing an AC hipot test than is observed when performing a DC hipot test.

AC hipot testing is often performed in multiple steps. This typically includes separating circuits and disconnecting appliances because some hipot testers do not have the output capacity to test the entire home. This lack of capacity is usually exhibited by the inability of the tester to reach the specified test voltage without going into failure mode. The operator must then determine if the failure condition is the result of excessive leakage current trip setting or if a breakdown of the insulation caused the failure. Many older testers lack current meters in their design. This makes it difficult for the operator to determine the nature of the failure condition. Circuit breakers must be shut off to isolate circuits and then each circuit must be retested separately.

When performing a DC hipot test, once the applied voltage charges up the capacitance of the DUT, the true leakage cur-

rent observed during a DC test is usually very small. The main advantage of DC testing over AC is that manufacturers can use smaller, lighter, more portable instruments and are able to test the complete home with the appliances, GFCIs, smoke detectors and fluorescent fixtures connected. This allows the manufacturer to test the entire modular home with a single connection as a single test. For these reasons, DC Hipot testing of manufactured and modular homes is quickly becoming the preferred method of testing. The only drawback is that you typically must ramp up the voltage to keep from having a false failure shutting down the hipot. This is due to the high initial total current, which includes charging current that flows until the circuit capacitance is fully charged, dielectric absorption current and the steady state leakage current. (Figure 2.)

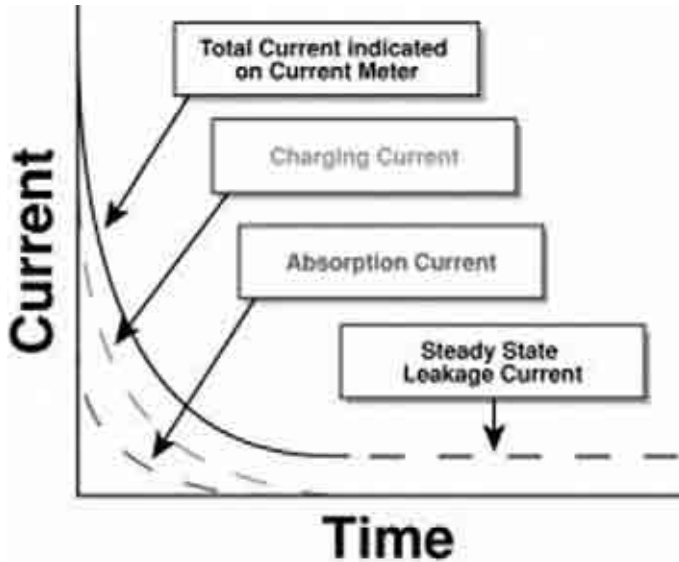


Figure 2 Direct Current vs. Time

The dielectric absorption current is the current that flows into a capacitor following its initial charge due to a gradual penetration of electrical stress into the dielectric. It is also the current that flows out of a capacitor following its initial discharge. This current represents a reversible stored energy that can be released after the applied voltage is removed. Setting the ramp time for a two- to three-second ramp should solve the problem of false failures by allowing enough time for the DUT to charge slowly and therefore keep the total current below the trip threshold. The trip level of the DC tester can be set to a lower level as compared to the trip level when performing an AC test. The leakage current observed when doing DC testing is a true indication of how good the insulation is because reactive current does not mask true steady state leakage current. The trip level of the hipot is typically adjusted around 1 milliamp when performing the test with DC, as compared to trip levels greater than 20 milliamperes when performing the test using an AC tester.

This brings up the issue of safety. Underwriters Laboratories (UL) and the American National Standards Institute (ANSI) ran tests in the 1960s to determine the human body's responses to different levels of electrical current. The tests were conducted using a 120 volt 60 hertz source.

They determined that on average, 0.5mA of current is the perception level and can produce a startle reaction. Higher current levels in the range of 5 to 10 mA will cause paralysis of the

extremities, effectively producing the inability to let go. Currents in the range of 20 to 40 mA between the extremities cause the muscles to contract painfully, making breathing difficult, and leading to asphyxiation. Current levels in the 40 to 70 mA range lasting for one second or longer cause ventricular fibrillation. Currents greater than 70 mA cause severe electrical burns and can cause cardiac arrest.

Based on the information above, performing a hipot test using a DC tester that has a trip level set for 1 mA would limit the shock hazard the operator could be exposed to as opposed to conducting a test with AC where the trip level could be set in excess of 20 mA. It is important to note that the DC hipot will shut down at a much lower current level limiting the exposure from the hipot.

However, this doesn't mean that the operator will only receive a 1 mA shock. The device under test, after being fully charged, can act like a capacitor and discharge its stored energy into a load such as a person who accidentally may come into contact with the circuit. This stored energy or charge on the DUT can be much greater than the energy available from the hipot. Stored energy is calculated by using the formula $V^2C/2$. For example, the capacitance value for a filter capacitor in a DC hipot tester might be 0.01 microfarads. This means that at 1530 volts the capacitor would deliver a charge of 11.7 milijoules of energy. A DUT could have a distributed capacitance of 0.05 microfarads, which at 1530 volts will deliver 56.2 milijoules of energy, five times the energy available from the hipot.

Another area of concern for manufacturers is potential damage to appliances within the manufactured home during a hipot test. Keep in mind that appliances within the manufactured home have already been hipot tested to comply with their product safety listing. If performed correctly, the test stresses the insulation between what are normally current carrying conductors and the dead metal or ground on the appliance. This is ensured by placing the power switch on the appliance in the on position, connecting the return of the hipot to the dead metal on the appliance and applying high voltage to the hot and neutral conductors. Performed in this way, the test applies an equal potential to both sides of the components within the circuit. This same method should be followed when testing the complete manufactured home. High voltage should be applied to both phases and to the neutral (the neutral must be isolated from ground) and the return should be connected to ground. All switches and circuit breakers should be in the on position. (Figure 3.) Connecting the hipot to the manufactured home in this manner will allow testing of the complete home with the appliances connected.

SUMMARY

There has been a trend towards DC Dielectric Withstand testing of modular and manufactured homes. There are advantages and disadvantages to both AC and DC testing which are listed in the chart below. DC testing seems to offer more significant advantages. Instruments are more portable and allow the complete home to be tested in one step. The hipot testers themselves are safer since the current trip setting can be set to a much lower level, thus reducing the shock hazard. More importantly, the test results obtained from DC leakage current readings give a true indication of the quality of the insulation system since the leakage current observed is due to the insulation resistance and not the distributed capacitance of the manufactured home as in AC testing. While AC testing has been the norm, advanced tech-

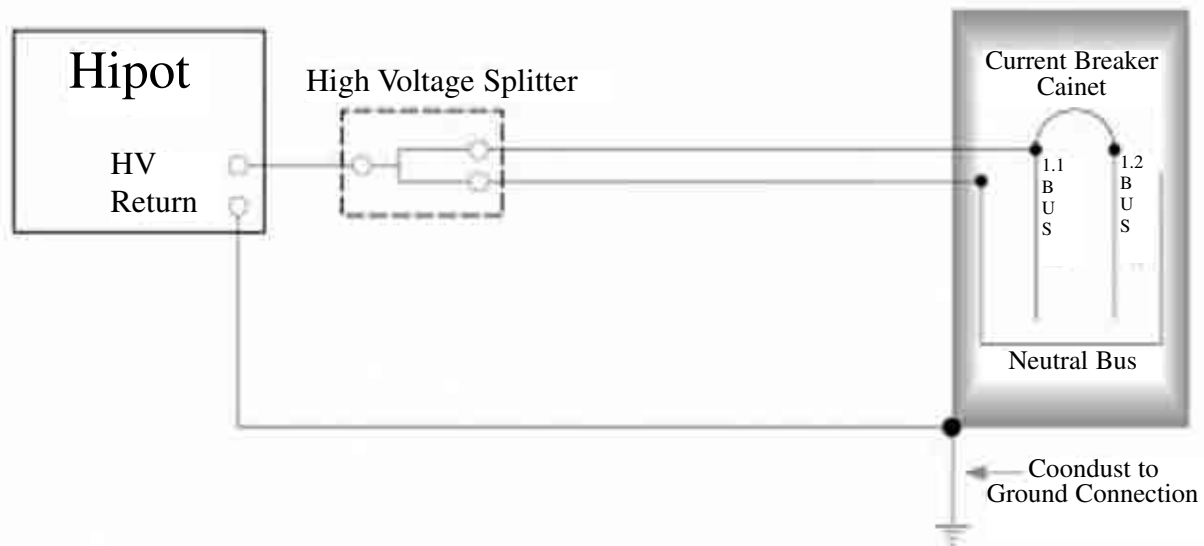


Figure 3 Hipot Tests of Manufactured and Modular Homes

nologies such as microprocessor control and electronic ramp and dwell timers have made DC testing a more viable and effective means of testing entire modular and manufactured homes.

DC TESTING

Advantages

- Smaller lightweight instrument
- Test entire home
- Safer due to less current
- Reads true leakage current

Disadvantages

- Must ramp up voltage
- Risk with not discharging DUT
- Must convert RMS to DC equivalent

AC TESTING

Advantages

- Test at specified RMS voltage
- No ramp required
- No need to discharge DUT

Disadvantages

- Larger tester required
- Usually cannot test entire home
- Safety risk due to higher current

WHY CALIBRATE TEST EQUIPMENT?

Fluke Corporation

You're serious about your electrical test instruments. You buy top brands, and you expect them to be accurate. You know some people send their digital instruments to a metrology lab for calibration, and you wonder why. After all, these are all electronic — there's no meter movement to go out of balance. What do those calibration folks do, anyhow — just change the battery?

These are valid concerns, especially since you can't use your instrument while it's out for calibration. But, let's consider some other valid concerns. For example, what if an event rendered your instrument less accurate, or maybe even unsafe? What if you are working with tight tolerances, and accurate measurement is key to proper operation of expensive processes or safety systems? What if you are trending data for maintenance purposes, and two meters used for the same measurement significantly disagree?

WHAT IS CALIBRATION?

Many people do a field comparison check of two meters, and call them "calibrated" if they give the same reading. This isn't calibration. It's simply a field check. It can show you if there's a problem, but it can't show you which meter is right. If both meters are out of calibration by the same amount and in the same direction, it won't show you anything. Nor will it show you any trending — you won't know your instrument is headed for an "out of cal" condition.

For an effective calibration, the calibration standard must be more accurate than the instrument under test. Most of us have a microwave oven or other appliance that displays the time in hours and minutes. Most of us live in places where we change the clocks at least twice a year, plus again after a power outage. When you set the time on that appliance, what do you use as your reference timepiece? Do you use a clock that displays seconds? You probably set the time on the "digitally challenged" appliance when the reference clock is at the "top" of a minute (e.g., zero seconds). A metrology lab follows the same philosophy. They see how closely your "whole minutes" track the correct number of seconds. And they do this at multiple points on the measurement scales.

Calibration typically requires a standard that has at least 10 times the accuracy of the instrument under test. Otherwise, you are calibrating within overlapping tolerances and the tolerances of your standard render an "in cal" instrument "out of cal" or vice-versa. Let's look at how that works.

Two instruments, A and B, measure 100V within 1%. At 480V, both are within tolerance. At 100V input, A reads 99.1V and B reads 100.9V. But if you use B as your standard, A will appear to be out of tolerance. However, if B is accurate to 0.1%, then the most B will read at 100V is 100.1V. Now if you compare A to B, A is in tolerance. You can also see that A is at the low end of the tolerance range. Modifying A to bring that read-

ing up will presumably keep A from giving a false reading as it experiences normal drift between calibrations.

Calibration, in its purest sense, is the comparison of an instrument to a known standard. Proper calibration involves use of a NIST-traceable standard — one that has paperwork showing it compares correctly to a chain of standards going back to a master standard maintained by the National Institute of Standards and Technology.

In practice, calibration includes correction. Usually when you send an instrument for calibration, you authorize repair to bring the instrument back into calibration if it was "out of cal". You'll get a report showing how far out of calibration the instrument was before, and how far out it is after. In the minutes and seconds scenario, you'd find the calibration error required a correction to keep the device "dead on", but the error was well within the tolerances required for the measurements you made since the last calibration.

If the report shows gross calibration errors, you may need to go back to the work you did with that instrument and take new measurements until no errors are evident. You would start with the latest measurements and work your way toward the earliest ones. In nuclear safety-related work, you would have to redo all the measurements made since the previous calibration.

CAUSES OF CALIBRATION PROBLEMS

What knocks a digital instrument "out of cal"? First, the major components of test instruments (e.g., voltage references, input dividers, current shunts) can simply shift over time. This shifting is minor and usually harmless if you keep a good calibration schedule, and this shifting is typically what calibration finds and corrects.

But, suppose you drop a current clamp — hard. How do you know that clamp will accurately measure, now? You don't. It may well have gross calibration errors. Similarly, exposing a DMM to an overload can throw it off. Some people think this has little effect, because the inputs are fused or breaker-protected. But, those protection devices may not trip on a transient. Also, a large enough voltage input can jump across the input protection device entirely. This is far less likely with higher quality DMMs, which is one reason they are more cost-effective than the less expensive imports.

CALIBRATION FREQUENCY

The question isn't whether to calibrate — we can see that's a given. The question is when to calibrate. There is no "one size fits all" answer. Consider these calibration frequencies:

- Manufacturer-recommended calibration interval. Manufacturers' specifications will indicate how often to calibrate their tools, but critical measurements may require different intervals.

- Before a major critical measuring project. Suppose you are taking a plant down for testing that requires highly accurate measurements. Decide which instruments you will use for that testing. Send them out for calibration, then “lock them down” in storage so they are unused before that test.

- After a major critical measuring project. If you reserved calibrated test instruments for a particular testing operation, send that same equipment for calibration after the testing. When the calibration results come back, you will know whether you can consider that testing complete and reliable.

- After an event. If your instrument took a hit — something knocked out the internal overload or the unit absorbed a particularly sharp impact — send it out for calibration and have the safety integrity checked, as well.

- Per requirements. Some measurement jobs require calibrated, certified test equipment — regardless of the project size. Note that this requirement may not be explicitly stated but simply expected — review the specs before the test.

- Monthly, quarterly, or semiannually. If you do mostly critical measurements and do them often, a shorter time span between calibrations means less chance of questionable test results.

- Annually. If you do a mix of critical and non-critical measurements, annual calibration tends to strike the right balance between prudence and cost.

- Biannually. If you seldom do critical measurements and don’t expose your meter to an event, calibration at long frequencies can be cost-effective.

- Never. If your work requires just gross voltage checks (e.g., “Yep, that’s 480V”), calibration seems like overkill. But what if your instrument is exposed to an event? Calibration allows you to use the instrument with confidence.

REDUCING GROUND BOUNCE IN DC-TO-DC CONVERTERS — SOME GROUNDING ESSENTIALS

Jeff Barrow

Electrical ground looks simple on a schematic; unfortunately, the actual performance of a circuit is dictated by its printed circuit-board (PCB) layout. What's more, ground-node analysis is difficult, especially for DC-to-DC converters, such as buck and boost circuits, which pound the ground node with large, fast-changing currents. When the ground node moves, system performance suffers and the system radiates EMI. But a well "grounded" understanding of the physics of ground noise can provide an intuitive sense for reducing the problem.

Ground bounce can produce transients with amplitudes of volts; most often changing magnetic flux is the cause. A loop of wire carrying current is essentially an electromagnet whose field strength is proportional to the current. Magnetic flux is proportional to the magnetic field passing through the loop area,

Magnetic Flux $\propto$ Magnetic Field $\times$ Loop Area

or more precisely,

$$\Phi_B = BA \cos \varphi$$

Where the magnetic flux, Φ_B , is the magnetic field, B , passing through a surface loop area, A , at an angle, φ , to the area's unit vector.

A look at Figure 1 gives meaning to the magnetic flux associated with an electric current. A voltage source pushes current through a resistor and around a loop of wire. This current is associated with magnetic flux encircling the wire. To relate the different quantities, think of grabbing the wire with your right hand (applying the right-hand rule). If you point your thumb in the direction of current flow, your fingers will wrap around the wire in the direction of the magnetic field lines. As those field lines pass through the loop, their product is magnetic flux, directed in this case into the page.

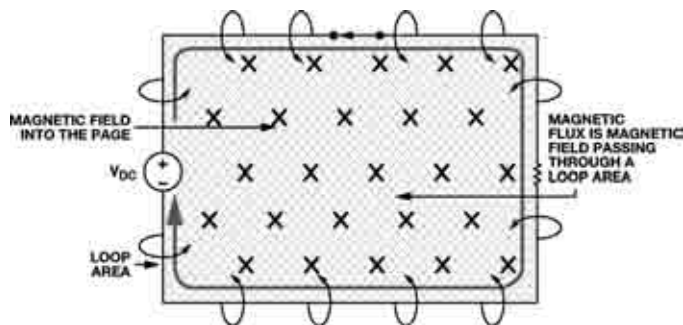


Figure 1. The right-hand rule.

Change either the magnetic field strength or the loop area, and the flux will change. As the flux changes, a voltage is induced in the wire, proportional to the rate of change of the flux, $d\Phi_B/dt$. Notice that either a fixed loop and changing current or a constant current and a changing loop area — or both — will change the flux.

Suppose, for example, that the switch in Figure 2 is suddenly opened. When current stops flowing, the magnetic flux collapses, which induces a momentarily large voltage everywhere along the wire. If part of the wire is a ground return lead, voltage that is supposed to be at ground will spike, thus producing false signals in any circuitry using it as a ground reference.

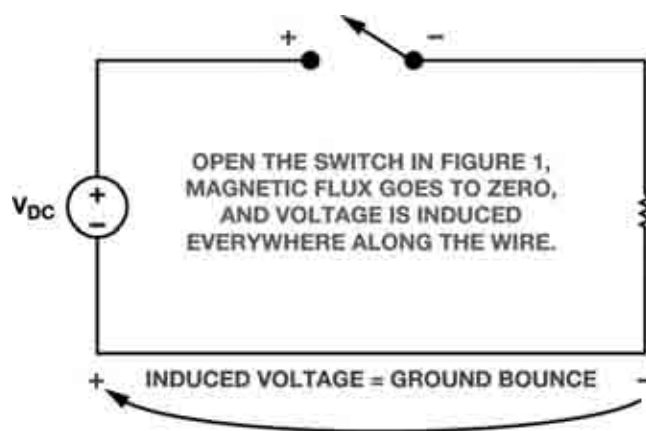


Figure 2. Effect of opening a switch.

Generally, voltage drops in printed-circuit-board sheet resistance are not a major source of ground bounce. 1-oz copper has a resistivity of about $500 \mu\Omega$ /square, so a 1-A change in current produces a bounce of $500 \mu\text{V}$ /square — a problem only for thin, long, or daisy-chained grounds, or precision electronics.

Charging and discharging of parasitic capacitors provides a path for large transient currents to return to ground. The change in magnetic flux from those changing currents induces ground bounce.

The best way to reduce ground bounce in a switching DC-to-DC converter is to control changes in magnetic flux — by minimizing both current loop areas and changes in loop area.

In some cases, as in Figure 3, the current remains constant, but the switching produces a change of loop area, hence a change of flux. In switch Case 1, an ideal voltage source is connected by ideal wires to an ideal current source. Current flows in a loop that includes a ground return.

In Case 2, when the switch changes position, the same current flows in a different path. The current source is DC and does not change, but loop area does change. The change in loop area means a change in magnetic flux, so voltage is induced.

Since a ground return is part of that changing loop, its voltage will bounce.

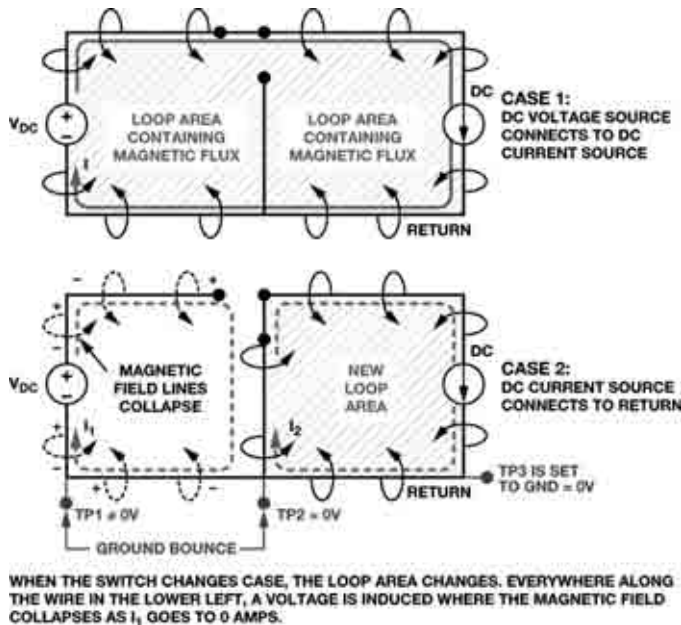


Figure 3.

BUCK CONVERTER GROUND BOUNCE

For the purpose of discussion, the simple circuit in Figure 3 is similar to — and can be morphed into — the buck converter in Figure 4.

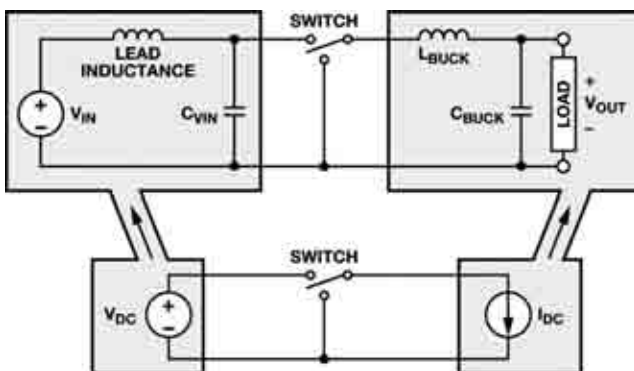


Figure 4. To a high frequency switch, an enormous C_{VIN} and L_{BUCK} look like a voltage and current source.

At high frequencies, a large capacitor — such as the buck input capacitor, C_{VIN} — looks like a DC voltage source. Similarly, the large output buck inductor, L_{BUCK} , looks like a DC current source. These approximations are made to help foster intuition.

Figure 5 displays how magnetic flux changes as the switch alternates between the positions.

The large L_{BUCK} inductor holds the output current roughly constant. Similarly, C_{VIN} maintains a voltage approximately equal to V_{IN} , so the input current is also more or less constant due to the unchanging voltage across the input lead inductance.

Although the input and output currents are roughly con-

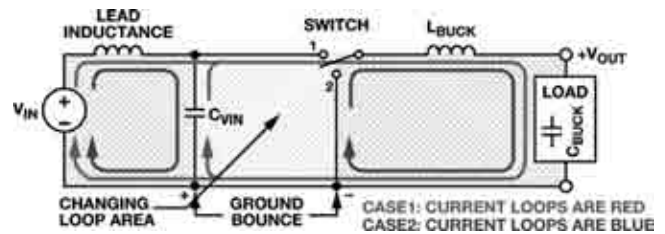


Figure 5. The effect of switching on loop area.

stant, as the switch moves from Position 1 to Position 2, the total loop area rapidly changes in the middle portion of the circuit. That change means a rapid change in magnetic flux, which in turn induces ground bounce along the return wire.

Actual buck converters are made with pairs of semiconductor switches, as shown in Figure 6. Although the complexity has increased with each figure, the analysis of ground bounce induced by changing magnetic flux remains simple and intuitive.

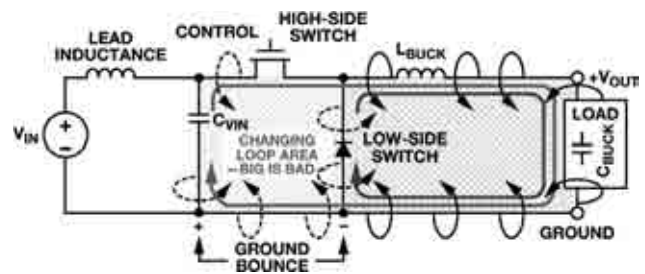


Figure 6. The basic principles are unchanged with semiconductor switching.

The fact that a change in magnetic flux will induce voltage everywhere along a ground return brings up the interesting question: where is true ground? Because ground bounce means a voltage on the ground return trace is bouncing with respect to some ideal point called ground, that point needs to be identified.

In the case of power-regulating circuits, true ground needs to be at the low end of the load. After all, a DC-to-DC converter's purpose is to deliver quality voltage and current to the load. All other points along the current return are not ground, just part of the ground return.

Since ground is at the low end of the load, and since changing loop area is the cause for ground bounce, Figure 7 shows how careful placement of C_{VIN} reduces ground bounce by reducing the portion of loop area that changes.

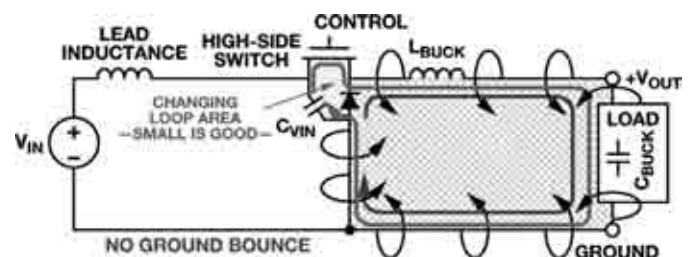


Figure 7. Careful placement of C_{VIN} greatly reduces ground bounce.

Capacitor C_{VIN} bypasses the top of the high-side switch directly to the bottom of the low side switch, thereby shrinking the changing loop area and isolating it from the ground return. From the bottom of V_{IN} to the bottom of the load, no loop-area or switch-current changes occur from one case to the next. Consequently, the ground return does not bounce.

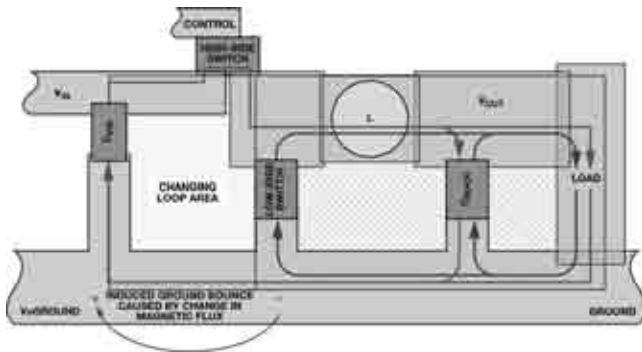


Figure 8. A bad layout results in a large change in current loop area from one switch case to the next.

The PCB layout itself actually determines the performance of the circuit. Figure 8 is a PCB layout of the buck schematic in Figure 6.

In the switch position shown in Case 1, with the high-side switch on, DC flow follows the outer red loop. In the switch position shown in Case 2, with the low-side switch on, DC flow now follows the blue loop. Notice the changing loop area, and hence, the changing magnetic flux. So, voltage is induced and the ground bounces.

The layout is realized on a single PCB layer for clarity, but using a second layer of solid ground plane would not fix the bounce. Before showing an improved layout, Figure 9 gives a quick example of where a solid ground plane may not be such a good idea.

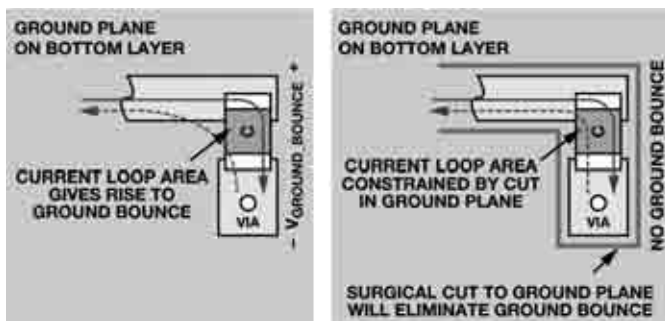


Figure 9. A solid ground plane is not always a good idea.

Here, a 2-layer PCB is constructed so that a bypass capacitor is attached at right angles to a top-layer supply line. In the example on the left, the ground plane is solid and uncut. Top trace current flows through the capacitor, down the via, and out the ground plane.

Because AC always takes the path of least impedance, ground return current rounds the corner on its way back to the

source. So the current's magnetic field and the associated loop area change when either magnitude or frequency of the current changes, hence the changing flux. The tendency of current to flow along the easiest path means that even a solid-sheet ground plane can bounce — irrespective of its conductivity.

In the example on the right side in Figure 9, a well-planned cut in the ground plane will constrain the return current to a minimum loop area and greatly reduce the bounce. Any residual bounce voltage that is developed in the cut return line is isolated from the general ground plane.

The PCB layout in Figure 10 uses the principle illustrated in Figure 9 to reduce ground bounce. A 2-layer PCB is designed so that the input capacitor and both switches are built over an island in the ground plane.

This layout is not necessarily the best, but it works well and illustrates a key principle. Notice that the loop area enclosed by the Case 1 and Case 2 currents is large. However, the difference between the two loops is small. The small change in loop area means a small change in magnetic flux — and so, a small ground bounce. (In general, however, also keep the loop area small — this figure strives to illustrate the importance of matching AC current paths.)

Additionally, in the ground-return island, where magnetic fields and loop area do change, any ground-return bounce is contained by the cut.

Also of interest, the input capacitor, C_{VIN} , may not at first glance appear to be located between the top of the high-side switch and the bottom of the low-side switch, as discussed in Figure 7, but closer perusal will reveal that it is. Although physical proximity can be good, what really matters is the electrical closeness that is achieved by minimizing the area of the loop.

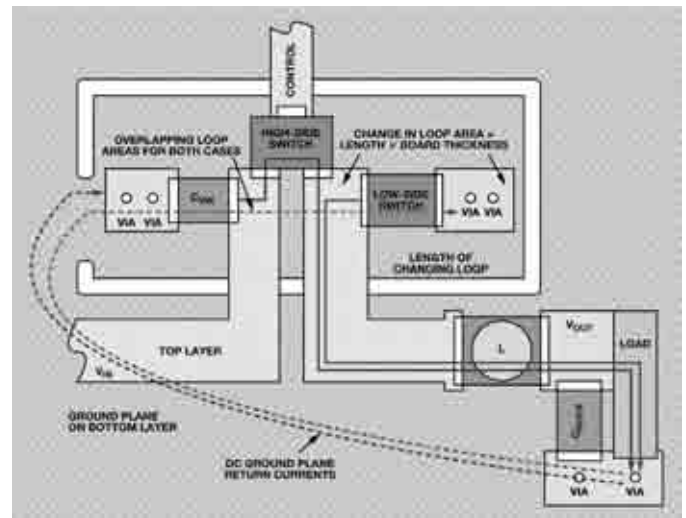


Figure 10. A good buck layout has a small change in loop area as between Case 1 and Case 2.

BOOST CONVERTER GROUND BOUNCE

A boost converter is essentially a reflection of a buck converter, so — as seen in Figure 11 — it is the output capacitor that must be placed between the top of the high-side switch and the bottom of the low-side switch to minimize the change in loop area.

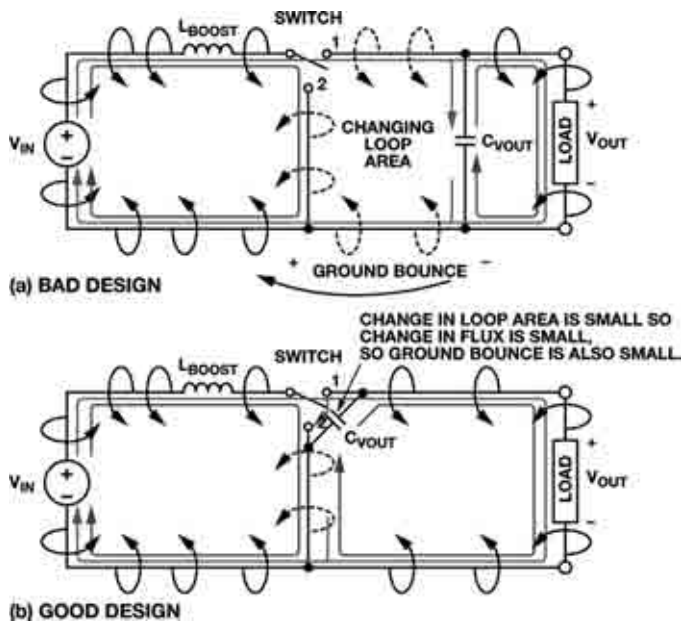


Figure 11. Boost converter means C_{VOUT} placement is critical in the same way that buck converter's C_{VIN} placement is critical. a) Bad design. b) Good design.

REVIEW

Ground-bounce voltage is induced principally by a change in magnetic flux. In a DC-to-DC switching power supply, the flux changes because high speed switches direct current between different current-loop areas. But careful placement of the buck/boost input/output capacitor and a surgical cut to a ground plane can isolate bounce. However, it is important to be watchful when cutting a ground plane, to avoid possibly increasing the loop area for some other return current in the circuit.

Also, a good layout locates true ground at the bottom of the load, with no changing loop areas or changing currents. Any other conductively associated point may be called "ground", but it is just a point along the return path.

OTHER USEFUL CONCEPTS FOR GROUND ANALYSIS

If you keep the following basic ideas in mind, you'll have a good feeling for what will and will not cause ground bounce. Figure 12 shows that conductors that cross at a right angle do not suffer magnetic interaction.

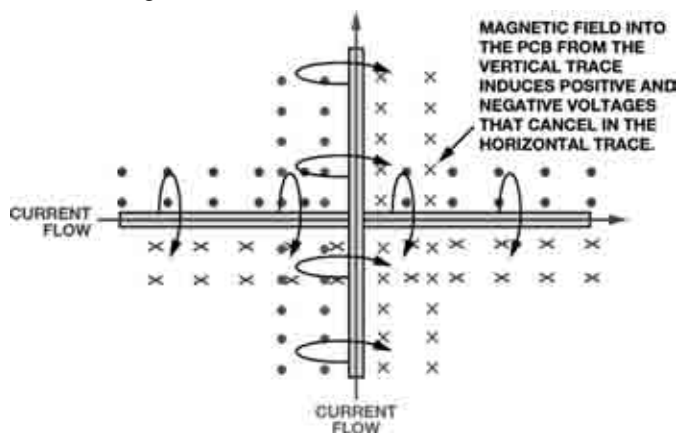


Figure 12. Conductors that cross at a right angle do not interact magnetically.

Magnetic field lines around parallel wires carrying equal currents flowing in the same direction cancel everywhere between the wires, so the total stored energy is less than what would be found for the individual wires. For this reason, wide PCB traces have less inductance than narrow traces.

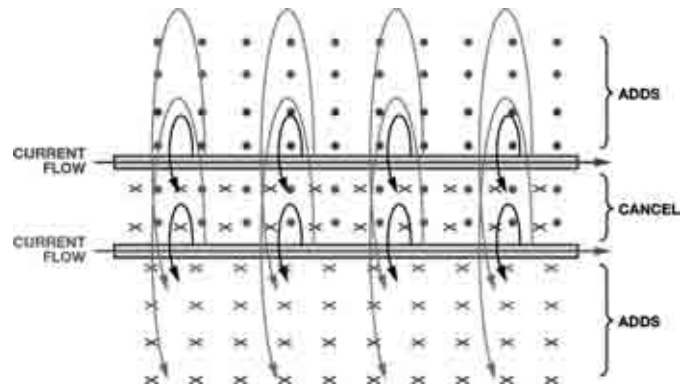


Figure 13. Parallel wires with currents flowing in the same direction.

Magnetic field lines around parallel conductors carrying equal currents flowing in opposite directions cancel everywhere outside of the conductors and add everywhere between them. If the inside loop area can be made small, then the total magnetic flux, and therefore the inductance, will also be small. This behavior explains why AC ground plane return current always flows under the top trace conductor.

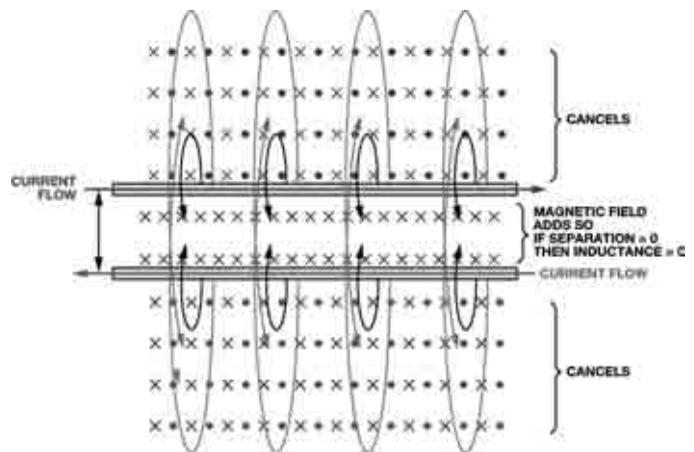


Figure 14. Parallel conductors with currents flowing in opposite directions.

Figure 15 shows why corners increase inductance. A straight conductor sees its own magnetic field, but at a corner, it also sees the magnetic field from the right-angled conductor. As a result, corners store more magnetic energy, and so, have more inductance than straight lines.

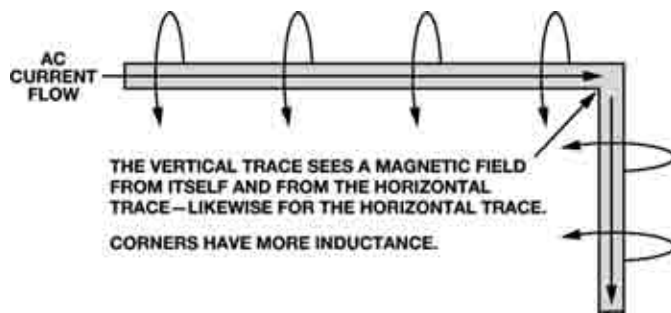


Figure 15. Why corners increase inductance.

Figure 16 shows that interruptions to the ground plane under conductors carrying current can increase loop area by diverting the return current, thus increasing loop size and facilitating ground bounce.

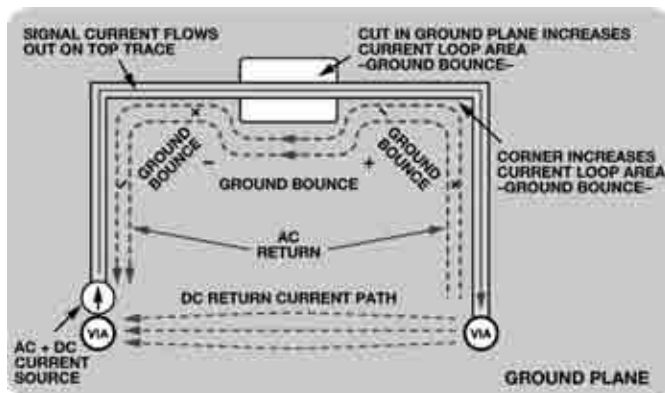


Figure 16. Return current takes the path of least impedance.

Component orientation does matter, as shown in Figure 17.

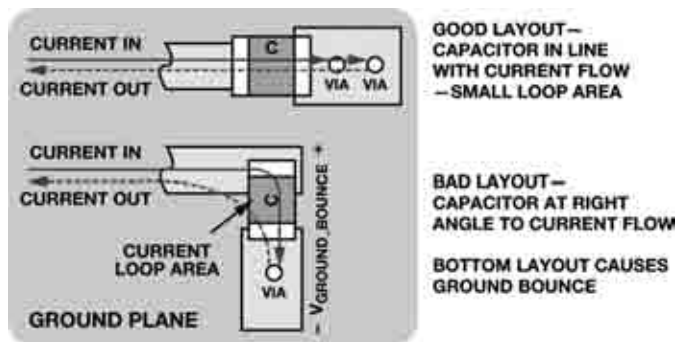


Figure 17. Effects of component orientation.

SUMMARY

Ground bounce is always a potential problem. For a monitor or TV, it can mean a noisy picture — for an audio device, background noise. In a digital system, it can lead to computation errors — even a system crash.

A careful estimation of parasitic elements followed by detailed simulation is a rigorous way to predict the magnitude of ground bounce. But to guide circuit-design intuition, it is necessary to understand the physics underlying its origin.

First, design the PCB so that the low end of the load is the true ground point.

Then, simplify the circuit dynamics by replacing large inductors and capacitors with current- and voltage sources. Look for the current loops in each switching combination. Make the loops overlap; where that is impossible, carefully cut out a small island of ground return such that only DC flows into and out of the opening.

In most cases, these efforts will give acceptable ground performance. If they don't, consider ground-plane resistance, then the displacement currents flowing in parasitic capacitors across all switches and down into the return path.

No matter what the circuit, the basic grounding principles are the same - changing magnetic flux needs to be minimized and/or isolated.

IMPEDANCE/RETURN LOSS: THE BASICS

Paul Vanderlaan, Product Development Engineer

There is a new requirement making waves in the telecommunications industry. Return loss (RL) is being specified in the newly ratified TIA/EIA TSB-95 Additional requirements for category 5 cabling and the proposed Category 5e and Category 6 documents. These specifications have brought a new awareness to the industry of an electrical parameter Belden has been promoting for a number of years. This article will give a brief explanation of this new specification, why it is important, and what things may adversely affect the performance of the RL in your network.

RETURN LOSS

Return Loss is one of many parameters regulated by the requirements established for Category 5e and 6 cables. It is a measure of the reflected energy from a transmitted signal. It is commonly expressed in positive dBs. The larger the value, the less energy that is reflected. The following figure illustrates return loss and its effect upon the original signal. In the top portion, the signal is injected upon the pair. As the signal travels down the pair, portions of the signal are reflected back to the transmitter. These reflections are caused by impedance discontinuities in the channel.

These discontinuities may be due to several things such as connectors, improper installation or handling or improper manufacture. Any energy that is reflected, reduces the power of the transmitted signal.

The lower half of Figure 1 shows the effects when the echo is reflected back to the right. The reflected echo combines with incoming data, effectively smearing the signal and making it harder for the receiver to resolve the signal. A simple analogy for RL would be talking into a large long pipe or tunnel. When one calls out down the tunnel, the caller can hear his or her own voice echoing back while the person at the other end hears a smear of multiple echoes along with the original voice. This echo distortion is similar to the effects of RL upon the transmitted signal.

Return loss can be calculated using the following equation:

$$RL = 20 \log |(Z_i - 100\Omega) / (Z_i + 100\Omega)|$$

Z_i = input impedance of the cable at a given frequency

In a lab environment, the value of a measured RL value is a negative number. However, in an attempt to avoid confusion, the standards refer to all measured values in a positive format. For comparison to a specification, this conversion is accomplished by placing a negative sign in front of the equation.

$$RL = -20 \log |(Z_i - 100\Omega) / (Z_i + 100\Omega)|$$

It is understood in the industry that the specifications in the standards may be converted into a negative format in the same manner. For simplicity, all the charts presented here will be in a negative format and all comparisons will be made to a converted standard.

WHY IS IT IMPORTANT NOW?

In 10BaseT systems, two pairs are used for the transmission of data. Figure 2 represents a simple model of this system. Transmitters are indicated by the gray triangles pointing into the pair while receivers are pointed in the opposite direction. Looking at one end of the cable, one pair transmits while another pair receives data from the opposite end. In this system, the transmitter only sends data and is not listening for data from the other end. The reflected energy in this system does not affect the transmitter. Rather, it slightly attenuates and distorts the signal as it travels down the length of the channel to the receiver at the far end.

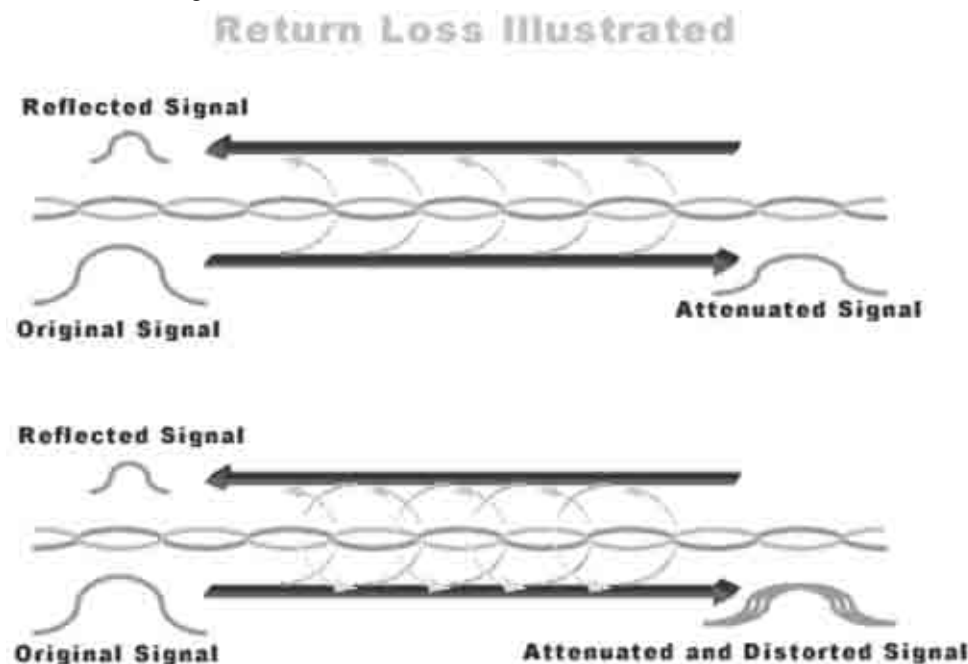


Figure 1

10BaseT Network Configuration

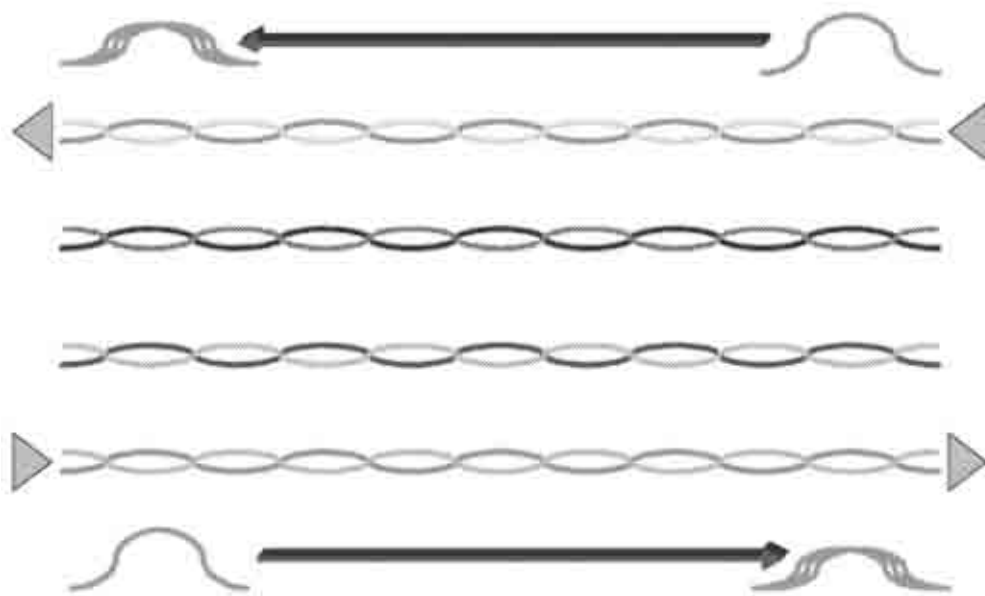


Figure 2

With newer systems such as 1000BaseT, the pairs at each end of the cable are now required to simultaneously transmit and receive data. This means that, as the transmitter is sending data, it is listening for data from the other end on the same pair. This would be similar to someone yelling down that tunnel while listening for the other person who is yelling at the same time. Any words arriving from the other person would suffer from the echo distortion. However, the echoes of the first person's voice are bouncing back at the same time as the distorted voice arriving from the other end. In a network, as the signal is sent from the near end, a portion is reflected back at the transmitter. This reflection mixes with incoming distorted data from the far end. This can make the interpretation of the transmitted data much more difficult.

In a network, as the signal is sent from the near end, a portion is reflected back at the transmitter. This reflection mixes with incoming distorted data from the far end making the interpretation of the transmitted data much more difficult.

WHAT AFFECTS RETURN LOSS?

Return loss is generated through variations in the impedance of the channel. These variations can take the form of connectors with high or low impedance values. The average input impedance of the patch cables may be significantly different from the horizontal cable's average.

Additionally, the cables may have large impedance variations at specific points due to cable design instability. This instability can be attributed to the construction of the pairs and singles and may be aggravated by various handling and installation practices.

In a simplified model, the channel is a highway for data transmission. Changes in impedance can be viewed as bumps and potholes which may, depending on their severity, slow or stop the traffic flow of data. The RL is a measurement of how many "cars" are turned back due to the bumps and potholes versus how many actually made it to the end of the road. In short, RL can be interpreted as smoothness or uniformity measurement method for your cable or channel.

CONNECTOR RETURN LOSS

Connectors are a weak link in the channel's performance. Specifically, the split pair in the RJ-45 type connector is the major culprit. The physical separation of the conductors

degrades the RL performance by disturbing the pair geometry. This separation of the pair generates an impedance discontinuity, causing signal reflections. Additionally, the near-end crosstalk (NEXT) compensation that some manufacturers performed on their older connectors aggravated the RL performance of the split pair. However, large improvements have been made to the new versions of connectors and this is becoming less of an issue making the cable performance more critical.

CABLE RETURN LOSS PARAMETERS

Cable return loss is regulated through two primary impedance parameters: the average input impedance and periodic impedance

Gigabit Ethernet Network Configuration

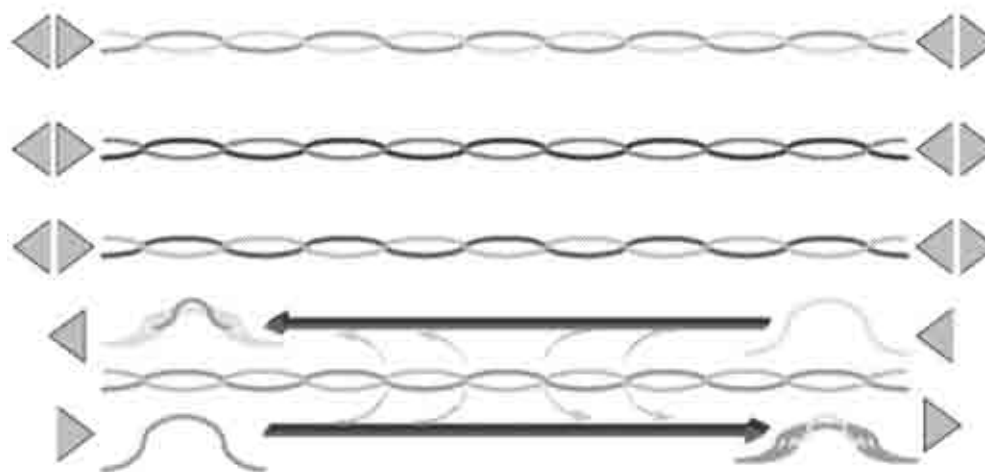


Figure 3

discontinuities. Each of these two parameters has several factors that affect their performance.

AVERAGE INPUT IMPEDANCE VS. RETURN LOSS

The unshielded twisted pair (UTP) systems Regulated by the ANSI/TIA/EIA -568-A document are 100 ohm systems. When the average input impedance of a cable is different from 100 ohms, the RL performance will decrease. The primary determining factor in the cable's average input impedance is the conductor-to-conductor spacing, however, such things as jacket tightness or shields can also play a large role. Sometimes, the jacket is utilized to ensure core integrity. If excessive amounts of jacket are removed, this may have a significant effect upon the average input impedance by raising the average input impedance for the exposed segment of core. Additionally, the cable can be stretched or crushed during the pulling process.

Typical impedance and RL charts of a Belden bonded pair cable are depicted here.

Typical Return Loss

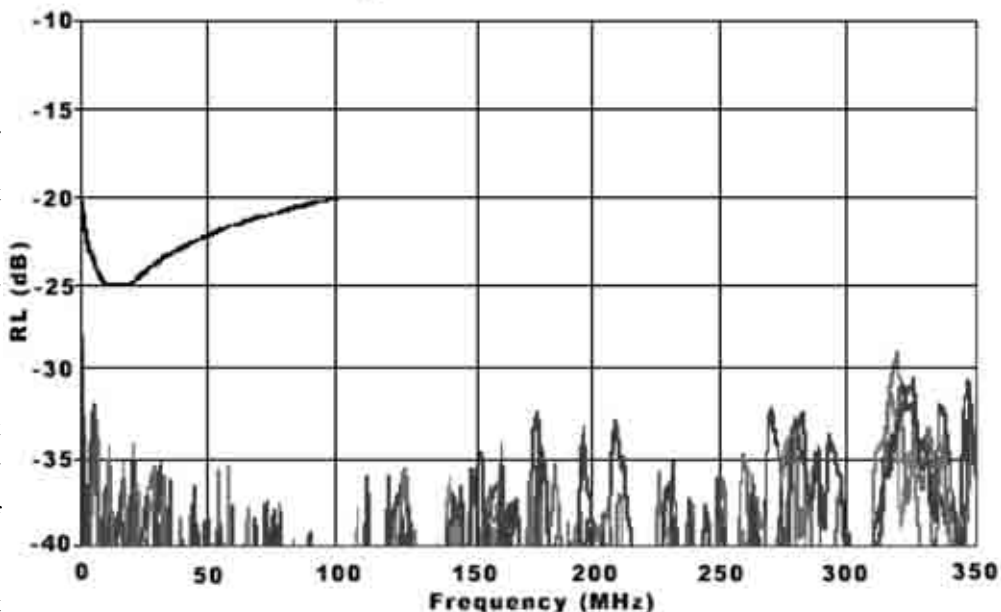


Figure 5

ing the cable to be as close to 100 ohms as possible. For illustrative purposes, the original impedance trace has been offset by a positive 7 ohms.

Typical Impedance

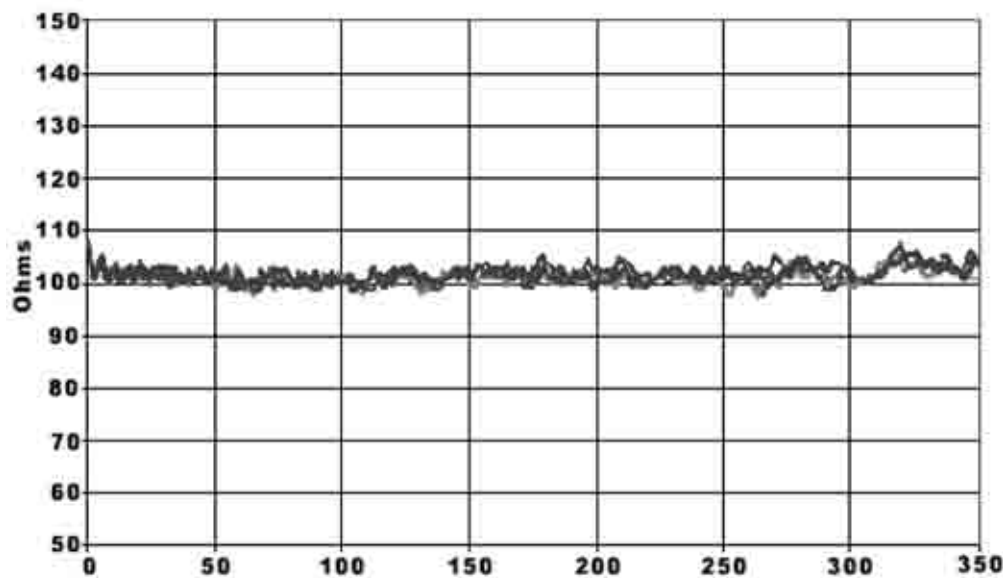


Figure 4

Notice that the impedance is very close to 100 ohms and the RL exhibits excellent performance with significant margin to the proposed Category 5e RL specification. The average input impedance for each pair is between 101.0 and 101.8 ohms and the standard deviation varies from a low of 1.4 ohms on one pair to a high of 1.6 ohms on the worst pair.

The following graphs indicate the importance of design-

As indicated by the above charts, the RL performance has been significantly degraded with the positive impedance offset. There is almost no margin left for connectors, cable instability, or installation practices. This illustrates the importance of designing a cable to be as close to 100 ohms as possible.

PERIODIC IMPEDANCE DISCONTINUITIES

Periodic impedance discontinuities are the second major contributors to the RL performance of a cable. These discontinuities are a strong indicator as to the quality of the cable. These discontinuities can be generated by a number of things. Inside the cable, such things as singles diameter and conductor to conductor spacing are critical. The following Figures 8 and 9 represent a competitor's category 5e impedance and RL performance respectively. The average input impedance is

between 103 and 105 ohms and the standard deviation varies from a low of 4.6 ohms on one pair to a high of 10.7 ohms on the worst pair. This is a strong indication that the pairs in this cable are not uniform and only provide marginal to failing performance, with no allowance for further installation effects.

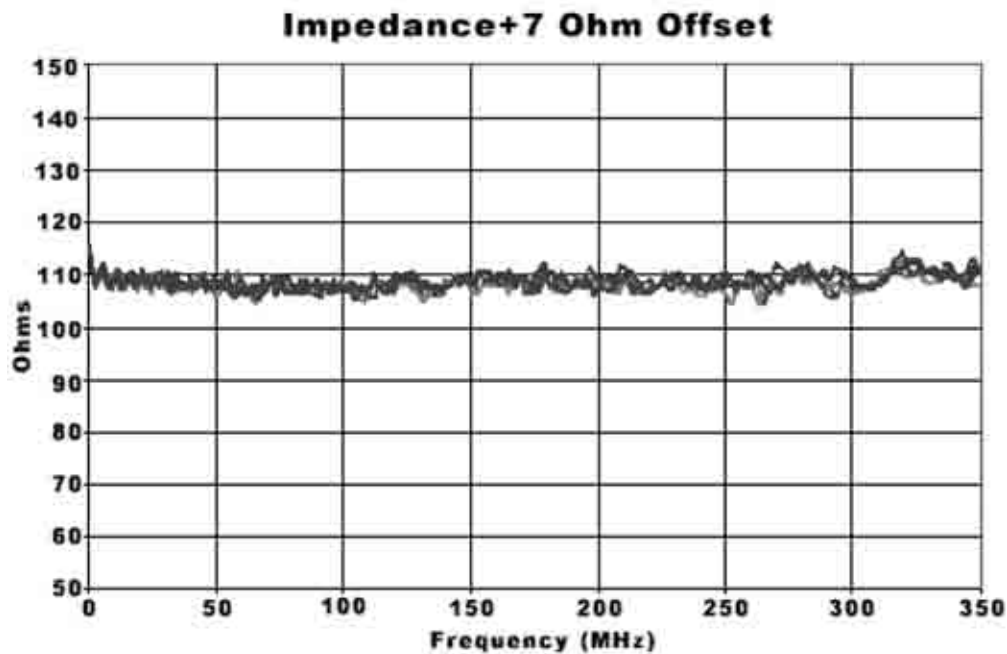


Figure 6

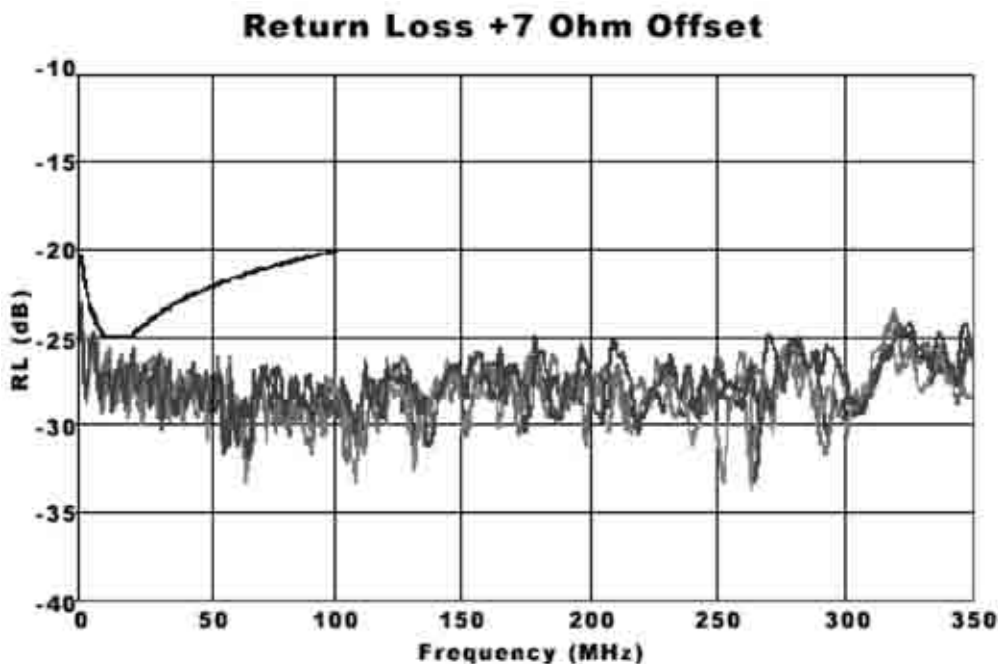


Figure 7

INSTALLATION EFFECTS

The final, and perhaps least understood, effect upon cable RL performance is the installation procedure. This involves a multitude of issues such as patch cable instability, package pay-off, pair untwist, jacket removal, cable bundling, bend radius, and service loops. Some hand-held test manufacturers brought to the TIA committee's attention the fact that most of the patch cables on the market were suffering from very unstable RL. It was determined that the patch cable's RL performance would vary widely with minor changes in position. Cable packages that impart a twist or knots into the cable could be adversely affecting the cable's RL.

Pair untwist has always been critical for NEXT performance. Add RL into the equation and it may be time to re-evaluate the neatness of your wiring closet. Bundling, service loops and bend radii once thought ok for Category 5 cabling now have serious implications to the end user.

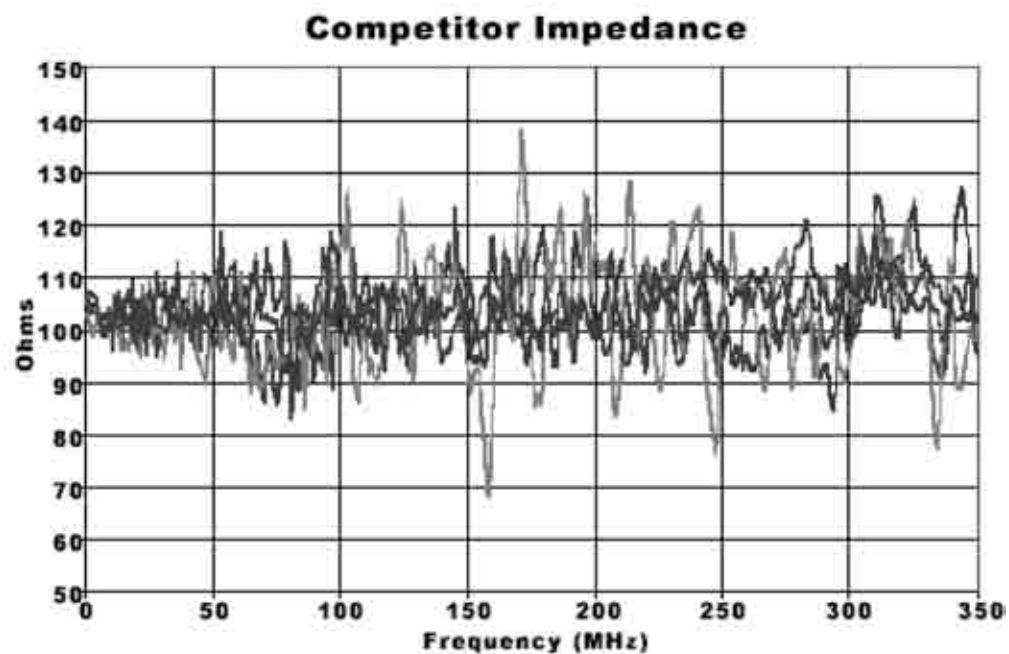


Figure 8

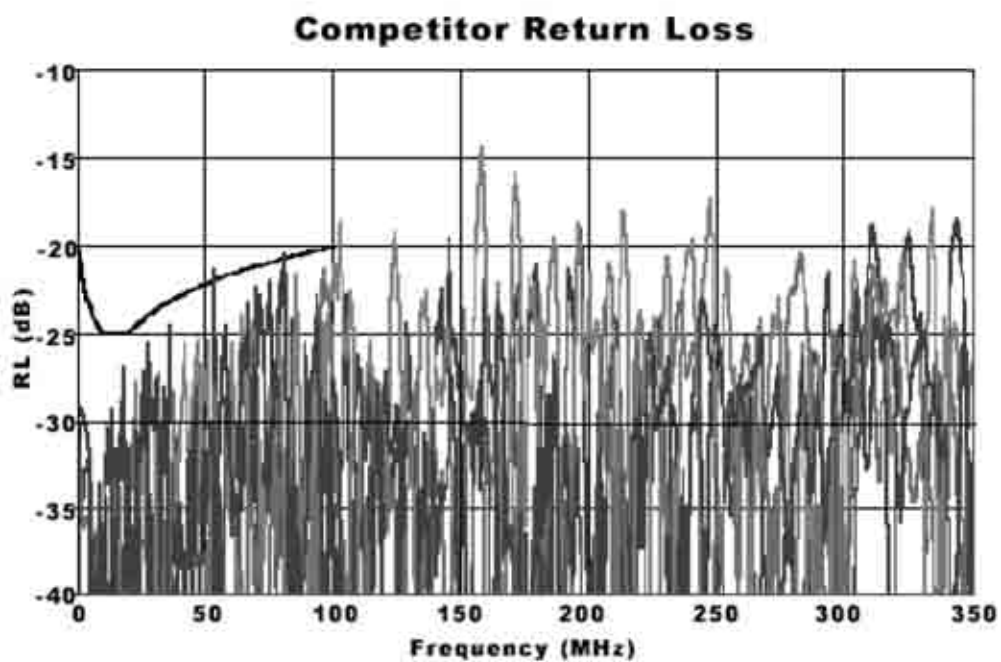


Figure 9

HOW STRAY VOLTAGE AFFECTS MULTIMETER MEASUREMENTS

Fluke Corporation

For most electrical measurements in the industrial environment, a high impedance digital multimeter or electrical tester is the appropriate tool. These test instruments have a relatively high-input impedance (>1 megohm), which means that when connected, they don't load the circuit under test. These test tools generally will not affect circuit operation or circuit measurements.

On the other hand, low impedance test instruments can seriously load down a circuit under test and, in some cases, can adversely affect circuit operation and circuit measurements. This can happen with sensitive control circuits or in many electronic circuits found within industrial machinery.

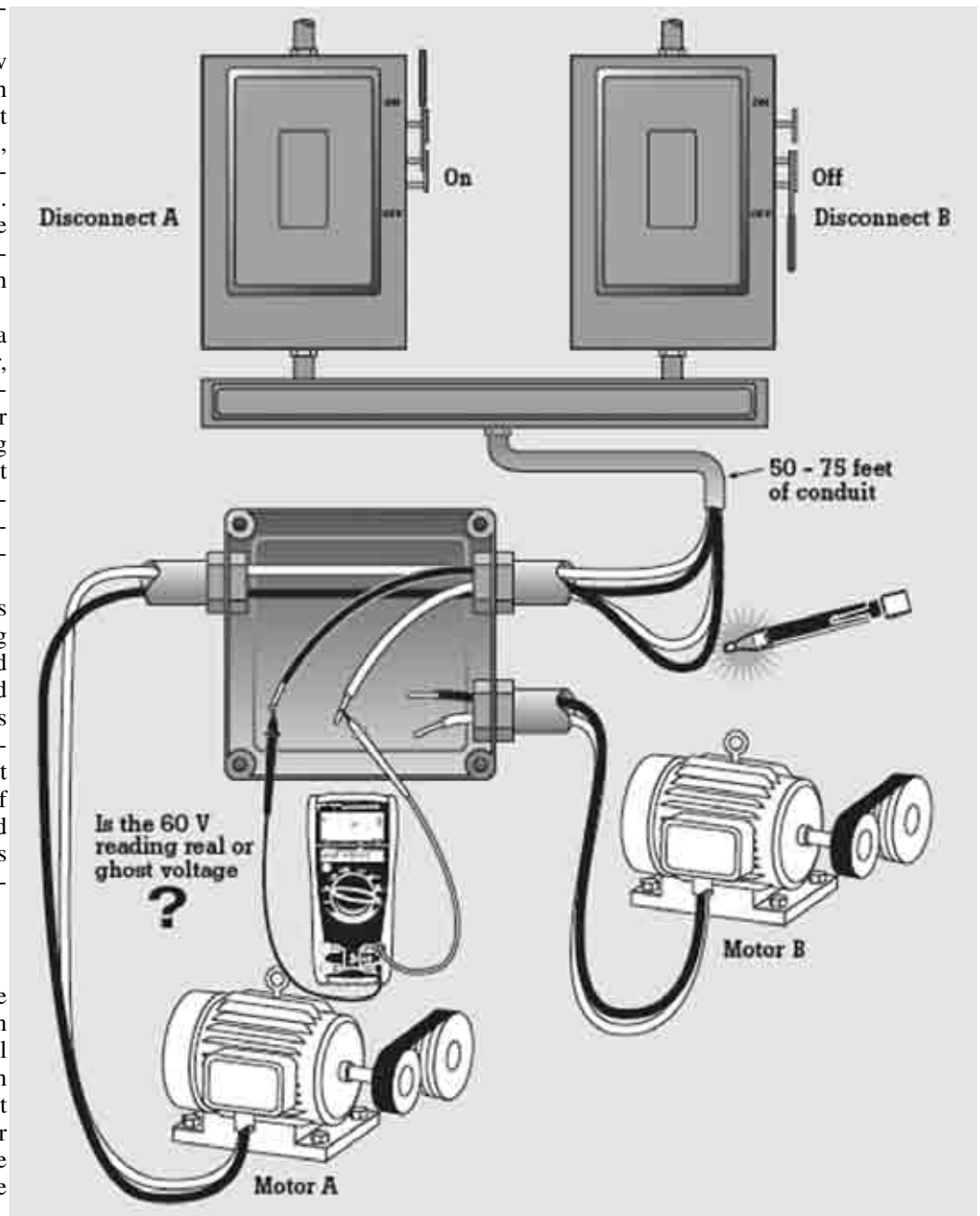
However, even with a high impedance multimeter, there's still one confusing measurement situation that can occur in facilities or manufacturing plants. It's called stray or ghost voltage, and it happens specifically when using a high impedance test instrument for day-to-day measurements.

Stray or ghost voltages occur from capacitive coupling between energized circuits and non-energized, non connected adjacent wiring. Because of this coupling effect and the multimeter's high impedance, it's not always possible to determine if the circuit under test is energized or de-energized, and this creates confusion for the person performing the test.

WHERE ARE STRAY VOLTAGES ENCOUNTERED?

The most common place to encounter stray voltage is in unused cable runs or electrical wiring in existing conduit. When facilities or buildings are built and wired, it's very common for electricians to pull extra wire through the conduit for future use.

These wires are typically left unconnected until needed, but are subject to capacitive coupling from the powered wires. Another example is an open ground or neutral on a 120 V branch circuit or in card cages where 120 volt control circuits are used to control assembly line or conveyor functions.



WHAT DOES STRAY VOLTAGE LOOK LIKE?

Generally, for most electrical measurements, a high impedance multimeter is the best tool, since you don't want the meter loading the circuit and affecting the circuit measurements. However, when dealing with capacitive coupling, a high impedance meter between ground or neutral to the unconnected cable or open connection will indicate some amount of voltage present. Typically this measured voltage reading may be as high as 50% of the energized voltage in the same proximity.

Is this voltage real? Yes, it is, but it's a static voltage, containing no real energy or current flow. When it comes to determining whether a circuit or connection is energized, this stray voltage reading presents a real source of confusion. Is the connection really hot or not?



THE FLUKE TL225 STRAY VOLTAGE ADAPTER TEST LEAD SET

The Fluke Stray Voltage Adapter Test Lead Set is an accessory that allows a high impedance multimeter to measure circuits, connections, cables or connectors subject to stray voltages. The adapter provides a low impedance load to the measured circuit, desensitizing the meter to low energy, spurious sources of interference. If the measurement points are energized with a hard voltage, the meter will simply display the voltage reading. If the measurement points contain a stray or ghost voltage, the meter will read very close to zero volts, indicating the circuit or connection is not energized.

WARNING

The stray voltage adapter is designed to be used in conjunction with high impedance digital multimeters for measurements on power circuits, to help determine whether the circuit is energized or not. The adapter presents a 3 k load to the circuit under test and thus will dissipate any stray voltage present if the circuit is not energized.

This adapter should not be used on low voltage control circuits or anywhere where the circuit under test could be adversely affected by this low impedance load. The adapter is designed to handle continuously applied power system voltages without damage, however proper use of this adapter is for intermittent use to determine whether a circuit is energized or not.

SAMPLE MEASUREMENT SCENARIO



Figure A

Figure A is a normal reading for an energized 120 volt branch circuit between hot and neutral. This reading is displayed on the meter with or without using the stray voltage adapter.



Figure B

Figure B is the measurement displayed with the high impedance DMM between neutral and an unconnected wire in the same conduit as a 120 volt branch circuit feed. Note the high impedance meter is displaying 33 volts. This is a capacitively coupled stray voltage reading.



Figure C

Figure C is displaying the result of the measurement from Figure B when the stray voltage adapter is placed in the circuit. Note that the reading is now 13 millivolts or very close to zero volts, a non-energized connection.

The low impedance presented by the stray voltage adapter dissipates the stray voltage. If the reading in Figure B was a hard voltage, the reading in Figure C would have been the same reading as in Figure B.

SAFETY

Testing for stray voltage is a measurement typically made for a short period of time, such as less than a minute. The stray

voltage eliminator module contained within the TL225 test lead kit is designed to withstand a continuous application of 1000 volts or less. The module has been tested to meet the IEC 1010-1 second edition CAT IV 600 V/CAT III 1000 V measurement category rating.

On a more personal safety note: If you've ever doubted your multimeter readings, consider the environment you're working in. Does it contain the ingredients for capacitive coupling? If it does, and if you need to rely on hot-or-not readings, you may want to consider adapting your multimeter. Stray voltage is confusing at best, and dangerous at worst. Don't be fooled!

WHOLE FACILITY UPS PROTECTION: A PRACTICAL SOLUTION TO CLASS-A DATA-CENTER POWER DENSITIES

Brad Roberts, PE, S&C Electric Company

The exponential growth in power density in computer rooms has resulted in major changes to the mechanical and electrical design criteria for data centers. As power densities approach 200 to 300Watts per square foot, making a facility's cooling system function in an uninterruptible fashion is a major undertaking.

This challenge can be even more difficult in a retrofit situation. The most logical way to accomplish non-stop cooling is by protecting the mechanical system loads with uninterruptible power. This creates the new challenge of keeping overall energy use as efficient as possible without compromise to the reliable uptime operation of the facility, while at the same time controlling total facility costs.

LESSONS FROM SEMICON FAB

The increasing power-density issues impacting data-center design and operations today are a problem that computer chip manufacturers have faced for many years.

As density and complexity of computer chip design accelerated, the power and cooling demands of semiconductor fabrication exploded. A semiconductor FAB has high heat-load tools that are very sensitive to power disturbances. In the past decade, major chip makers have applied large medium-voltage UPS systems to protect all of the electrical and mechanical loads. Because these are very large facilities with loads of up to

20,000kVA or higher, applying UPS protection with maximum operating efficiency was a major concern. Using conventional low-voltage double-conversion UPS was ruled out. Large rotary UPS systems have been applied, and, most recently, medium-voltage, off-line static UPS systems have been used.

MEDIUM-VOLTAGE STATIC UPS

The most efficient method of protecting a very large electrical load with uninterruptible power is off-line UPS using low-voltage inverters stepped up to medium-voltage (typically 15,000V in a 1/4-cycle response configuration).

Figure one shows a one-line diagram of typical off-line UPS rated at 5,000kVA at medium voltage.

The fast, 1/4-cycle response is achieved with a medium-voltage power electronic switch (PES) which provides rapid disconnect from the utility power source when a disturbance occurs.

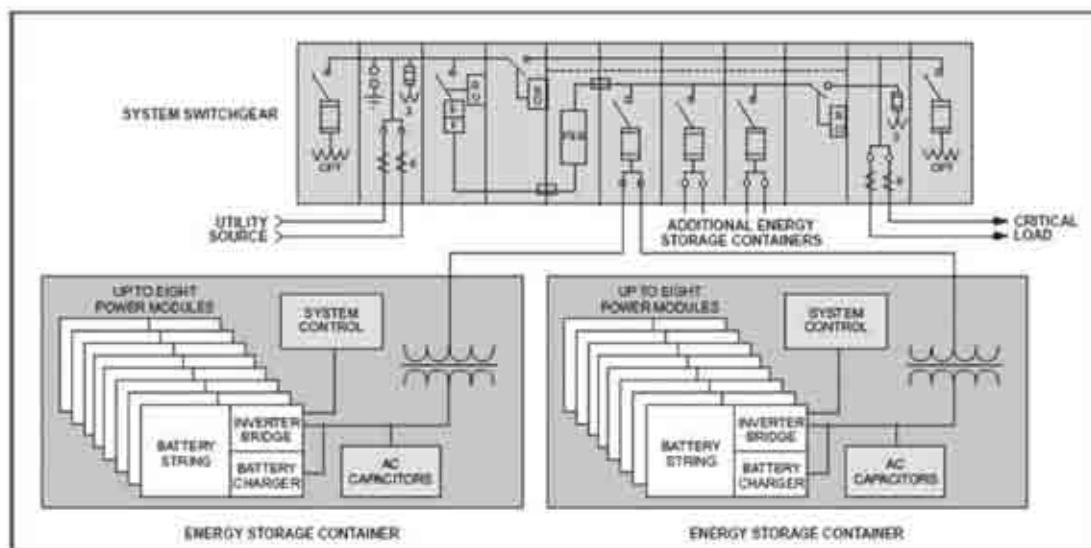
This approach provides seamless power flow to the critical load and achieves operating efficiencies of 99 percent or greater. Conventional UPSs in a double-redundant design can have efficiencies well below 90 percent, in most cases. This approach is simply not practical for powering mechanical loads.

The very high efficiency of these high-powered, medium-voltage UPS systems is a simple solution for protecting chillers, chilled water pumps and fans in computer-room air conditioning

(CRAC) units. Good electrical design dictates that chillers with motors larger than 500hp should be specified at 5kV ratings. Matching the main mechanical loads with a 5kV UPS is much more practical than using low-voltage UPS systems with step-up transformers.

SERIES VS. PARALLEL UPS REDUNDANCY

Once the decision is made to add uninterruptible power protection to the mechanical loads to achieve Level-A or -B



Single-line diagram of medium-voltage application.

Fig. 1 - simplified one-line diagram for a 5,000kVA medium-voltage UPS system

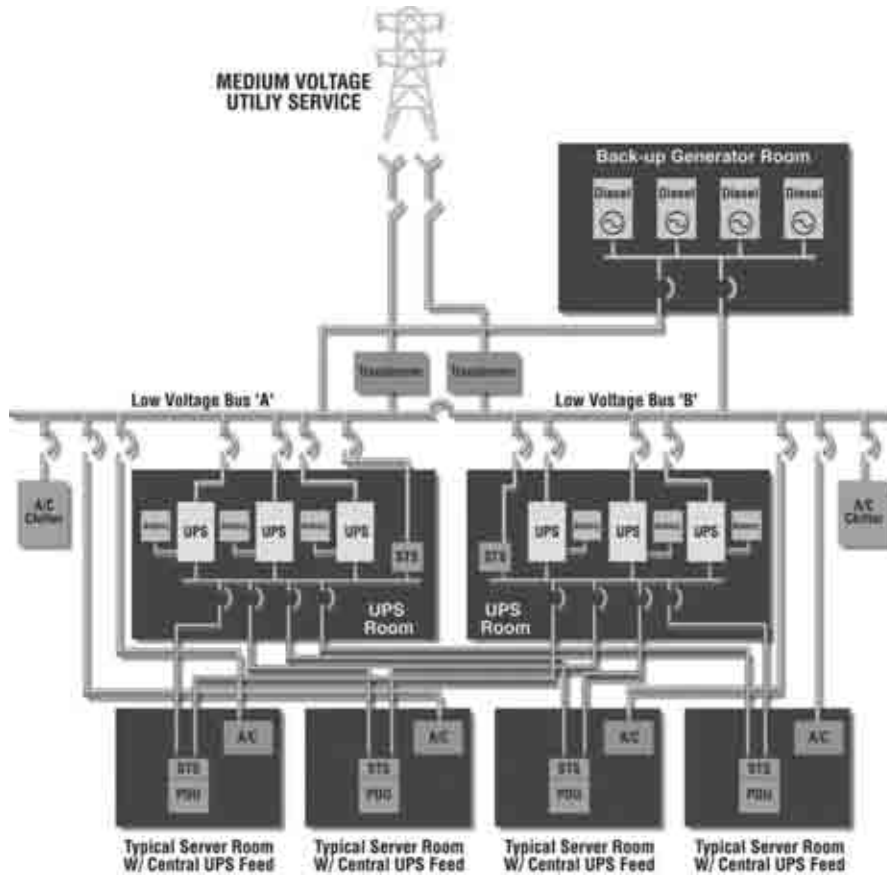


Fig. 2 - conventional Tier III or IV data-center electrical system.

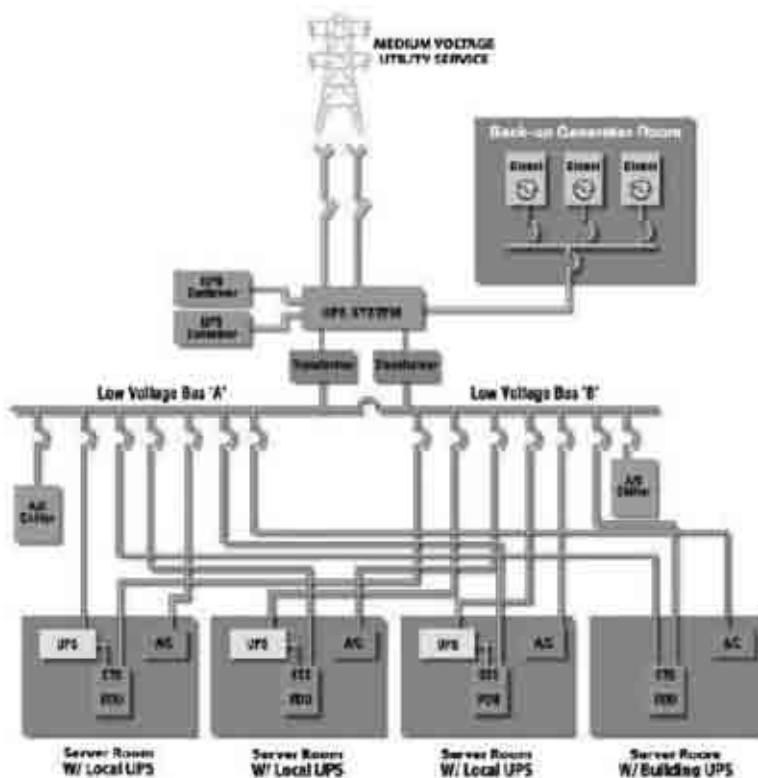


Fig. 3 - series-redundant power system combining redundant power protection with Class-A cooling.

continuous cooling, the expanded use of uninterruptible power in a data center can be leveraged to improve overall power system reliability and potentially be more cost effective. Figure two shows a simplified one-line diagram of an electrical system for a typical critical data-center environment designed to Tier III or IV reliability.

The series-redundancy approach (in figure three) provides several advantages beyond the addition of UPS protection for the mechanical systems.

Those added benefits are:

- much higher overall UPS efficiency, which would reduce energy costs due to power interruptions or losses;
- better isolation between critical-load segments as second-tier UPS systems are located closer to the loads;
- improved battery life in the smaller power systems, because the building-level UPS eliminates nuisance voltage dips that adversely impact battery life;
- elimination of the expensive complex power wiring associated with double-redundant UPS schemes; and
- less building space used for UPS, since medium-voltage UPS systems can be installed outdoors.

CONCLUSION

The series-redundancy approach described in this article provides maximum power system flexibility and reliability to manage the higher power densities being experienced in today's critical computing and data-center environments.

Accommodating large power loads can now be addressed with greater flexibility for data center facilities and infrastructure systems designers.

The addition of medium-voltage UPS systems that can power complete building mechanical systems as well as provide very high operating efficiencies is both available and field proven.

Brad Roberts is Power Quality Systems director for S&C Electric Company which specializes in low- and medium-voltage power-protection systems.

GROUND BOND OR GROUND CONTINUITY? TAKING YOUR CUSTOMER'S SAFETY TO THE NEXT LEVEL

The Slaughter Company

INTRODUCTION

Most manufacturers familiar with safety testing are well aware that a verification of the ground circuit on electrical products is necessary for safety agency compliance. In fact, verifying that the ground circuit of an electrical product is intact is required by most safety agencies as a 100% production line test (a test that must be performed on all manufactured units prior to shipment). What most manufacturers don't know, however, is that there is more than one way to test a product's ground circuit. While the Ground Continuity test has found a home in the majority of safety testing routines, more test engineers and technicians are discovering the benefits of the Ground Bond test.

For years, the only means by which to test the continuity of a product's earth ground conductor was the Ground Continuity test. This low-voltage, low-current test usually consists of a small DC voltage source, a simple measuring circuit, and an indicating device. The test instrument can be as simple as a battery-operated clip and buzzer, or as advanced as an automated electrical safety tester. Yet the concept remains the same: apply a small voltage across the ground wire of a product, measure the current through it, and make sure the resistance is within an acceptable level. Ensuring that the safety ground wire is continuous meets most safety agency standards, but as we will discuss, that may not be good enough.

GROUND CONTINUITY SHORTCOMINGS

An undeniable shortcoming of the Ground Continuity test is that it fails to verify the integrity of the earth ground conductor. Why is this important? The earth ground conductor is tied directly to the chassis of a Class I product (a product with a metallic or other conductive enclosure) in order to direct any fault current back to ground in case of an insulation failure. Determining that there is continuity between the ground plug and the metal chassis of the electrical product is desirable because it indicates that there is a path for fault current to return

to ground; however, continuity alone doesn't justify whether or not the wire is capable of handling the current it is meant to conduct.

Since the Ground Continuity test is a low current test, it will only indicate if there is a connection between a product's enclosure and its ground plug (see Figure 1.0). This connection could consist of one strand of wire or one-thousand strands of wire – as long as the measured resistance is below the specified preset value, the test will indicate a PASS condition. Yet how will this single strand or bundle of conductors handle the fault current likely to be imposed on it? Many household time-delay fuses and/or circuit breakers can handle a 200% current overload condition for up to two minutes; it is only logical that the earth ground conductor on any product operating under utility power is capable of handling the same condition. Yet the Ground Continuity test will not yield this important piece of information.

A BETTER WAY TO TEST

In today's on-demand world, electrical products are ever-present. The Ground Bond test provides the high current levels needed in order to ensure that the earth ground conductor of a product can handle any fault current likely to be imposed on it (see Figure 2.0). In fact, most Ground Bond tests are specified to be performed at two times the rating of a product's fuse or branch circuit for up to two minutes. Testing under these conditions not only verifies the presence of a continuous earth ground conductor, but also verifies the integrity of that conductor.

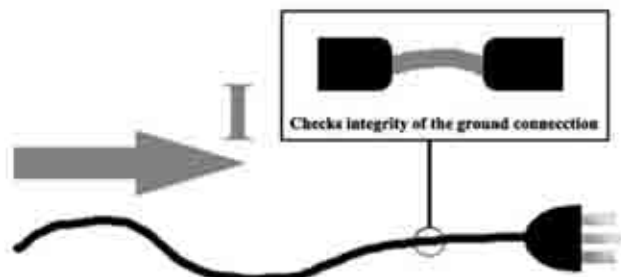


Figure 2.0: Ground Bond Test Theory

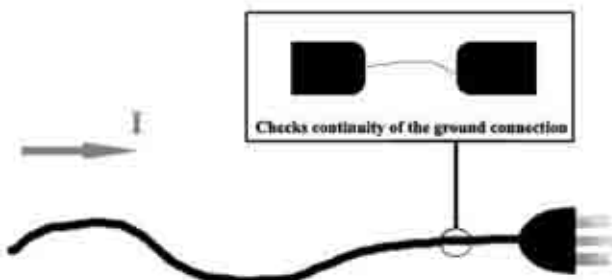


Figure 1.0: Ground Continuity Test Theory

The Slaughter Model 2630 is a 30 amp Ground Bond tester with multiple Memory Locations and Auto-offset capability (see Figure 3.0). Features like these make it easy on manufacturers of multiple products to test quickly and easily in a production environment. With multiple programmable Memory Locations, a test operator can set up, store, and recall param-

ters for different devices under test (DUT's). For example, say a manufacturer sells toaster ovens domestically in the U.S. and overseas into the European Union. With a Slaughter 2630, the test operator can set Memory Location 1 to test at 60 Hz, 30 amps, and 60 seconds. Meanwhile, the operator can also set Memory Location 2 to test at 50 Hz, 25 amps, and 120 seconds. Recalling and toggling between Memory Locations is as easy as pressing a button, allowing the test engineer to quickly and efficiently test products to both countries' specifications.



Figure 3.0: Slaughter Company Model 2630

Many manufacturers are concerned about offsetting test lead resistance when performing a Ground Bond test. After all, one of the most important pieces of information which a Ground Bond verifies is the resistance measurement – it is crucial that this measurement be accurate. Instruments like the Slaughter Model 2630 compensate for this issue by incorporating an “Auto-offset” feature. With this feature, the test operator can intentionally subtract (hence the term “offset”) the resistance of the test leads and any other fixturing during a Ground Bond test, making the final resistance measurement of the DUT's earth ground conductor more accurate. This feature assures that a good test is being performed.

SUMMARY

The Ground Bond test presents manufacturers with the ability to perform a better, safer method of testing an electrical product's earth ground conductor. Routine Ground Bond testing will help to ensure that all products shipped from the factory meet the highest safety standards, giving customers and manufacturers piece of mind, while preventing frivolous injury lawsuits. For manufacturers considering making the switch to Ground Bond testers, the principle of the Ground Bond test and the operation of the tester itself are not unlike that of the Ground Continuity test. Thus the transition from one instrument to the other is seamless. As of this writing, Ground Bond testing is usually done as a type or design test – a rigorous test performed in a laboratory environment. Yet more and more manufacturers are starting to rely on the Ground Bond test in the production environment as well. The simple fact is that the Ground Bond test is a better test, and a better test yields a safer product.

SHORT CIRCUIT CURRENT RATINGS & SOLID STATE RELAYS

Dr. Oscar Montero, Crydom, Inc.



NEW CHALLENGES FOR INDUSTRIAL PANEL BUILDERS

The 2005 National Electrical Code now requires most control panels to be marked with their short-circuit current rating (SCCR). This change affects all industrial control panels (409.110), industrial machinery panels (670.3(A)), and non-residential HVAC equipment rated greater than 60A (440.4(B)). Furthermore, all industrial control panels listed to UL508A must be marked with their SCCR. Supplement SB in UL508A, which became effective on April 1, 2006, is referenced by the NEC as an approved method for establishing the SCCR of a panel.

As with most every change to the NEC, safety is the primary concern of this new requirement. Under abnormal operating conditions, such as an electrical fault, a control panel may be subjected to thousands of amperes of let-through current before any protective device(s) inside the panel clears the fault. Such an event may cause severe damage to power components and electrical wiring, which can compromise the integrity of the Panel and result in injury to nearby personnel.

Proper matching between the maximum available current from the power supply and the SCCR for the panel is fundamental to ensure safety. From the Panel users point of view, Panels with a higher SCCR allows them the flexibility to connect their Panel to electrical systems with different available currents. From the Panel builder's point of view, establishing this higher SCCR may represent significant challenges and additional costs.

ESTABLISHING THE SCCR FOR CONTROL PANELS

Even though supplement SB from UL508A defines how the SCCR for an Industrial Panel is established, determining the Panel's actual SCCR may not be so straightforward. The simplest method to obtain the Panel's rating is by analyzing the individual power components in each branch of the circuit. The component with the lowest rating determines the SCCR for the entire branch. Subsequently, the branch with the lowest rating

Typical Components found in a branch circuit of an industrial control panel:

Circuit Breakers	SSRs
Contactors	Drives
Motor Controllers	Fuses
NEMA Contactors	Transformers
Terminal Blocks	Receptacles
Meter Sockets	Switch Units

determines the SCCR for the entire panel.

Despite the fact that the SCCR rating for SSRs was not available in the past (nor was such a rating required) it is obvious from the above example that this is a critical part of determining the rating for the entire panel. Per UL508A supplement SB, components that do not have such a rating are given one based upon their specific category. SSRs, which do not have a specific category, are considered to fall under "Switches", "Switch Units", or "Motor Controller, 0-50HP". The rating for unmarked components in these categories is 5kA, and the use of such component in a branch circuit effectively reduces the entire

Extract of Data from UL 508A Table SB4.1

Assumed maximum short circuit current rating for unmarked components
(7/1 April 23, 2006)

Component	SCCR, kA
Bus bars	10
Circuit breakers (including GFCI type)	5
Current meters	5
Fuseholder	10
Industrial control equipment	
a. Auxiliary devices (overload relay)	5
b. Switches (other than mercury tube type)	5
c. Mercury tube switches	
- Rated over 60 amperes or over 250V	5
- Rated 250 volts or less, 60 amperes or less, and over 2 kVA	3.5
- Rated 250 volts or less and 2 kVA or less	1
Motor controller, rated in horsepower (kW)***	
a. 0-50 (0-37.3)	5***
b. 51-200 (38-149)	10***
c. 201-400 (150-298)	18***
d. 401-800 (299-447)	30***
e. 801-900 (448-671)	42***
f. 901-1500 (672-1103)	85***
Meter socket base	10
Miniature or miscellaneous fuse	10**
Receptacle (GFCI type)	2
Receptacle (other than GFCI type)	10
Supplementary protector	0.2
Switch unit	5
Terminal block or power distribution block	10

panel to the same rating.

It must be realized that any rating from this table is subject to meeting what UL defines as conditions of acceptability. It is strongly recommended to check with UL about those conditions for any unmarked component that may be included in the Panel. Moreover, it should be noticed that the rating assigned to the SSR may have an impact on determining the rating for the whole Panel, as will any other power component inside the Panel.

ESTABLISHING THE SCCR FOR SOLID-STATE RELAYS

Per UL508A, short-circuit current ratings can be conveniently established for individual power components, or for combination of power components, or for the Control Panel as a whole. Crydom has elected to test a combination of SSRs with protective devices (fuses initially) in order to meet the conditions of acceptability necessary to assign the standard 5kA rating to the combination. However, most Crydom customers desire a SCCR rating higher than 5kA for their panel in order to be more competitive in the market. For this reason, Crydom is undertaking a series of tests in order to significantly increase the UL approved SCCR ratings for their relays.

The tricky part is selecting the right fuse for not only the application, but also for the desired SCCR rating for the combination. It is understood that under sizing the fuse may compromise performance, while over sizing the fuse may impact the safety of the Panel. Not to mention add unnecessary cost. To further complicate the issue, fuses of the same physical size may have different current ratings (i.e. a 60A fuse is the same physical size as a 45A fuse). This is a significant UL concern, as field service technicians could easily replace a fuse with one of identical size but having a higher current rating. Such an error could potentially result in damage to the relay, the load, or nearby personnel.

Therefore, UL requires that the relay-fuse combination be tested with an “umbrella fuse”. That is, the fuse used in the combination must have the highest possible current rating available for that particular fuse package. Since UL approval with a rated fuse covers all fuse ratings up to that value, the “umbrella fuse” method adequately addresses this concern. Crydom’s test plan involves multiple relays of different load-current ratings in combination with the highest possible “umbrella fuse” combination. This not only meets UL’s safety requirements, but also provides panel builders with flexibility in selecting the right relay for their application and their specific SCCR requirements.



Similar to fuses, solid-state relay manufacturers tend to follow a typical industry-standard footprint. However, unlike fuses, each manufacturer’s relays may have significant design differences that affect thermal performance, power dissipation, mechanical stress/fatigue, etc. Therefore, the “umbrella” concept does not apply in the same manner as it does for fuses. So simply substituting one relay with an “equivalent” relay from another manufacturer will not likely result in an equivalent short-circuit current rating.

It should be remembered that SCCR is strongly related to safety, and therefore great caution must be used when changing solid-state relays in control panel.

WHO SHOULD BE CONCERNED OVER SCCR?

While the new NEC code focuses primarily on the North American market, Panel Builders selling outside of the US may also be affected by the change. Any panel requiring UL Listing, regardless of its final destination, must be marked with a SCCR. In addition, some regions outside of the US may enforce NEC 2005 as an additional safety measure for local installations. Panels in such locations must also have their SCCR clearly marked.

To add to the confusion, some states in the US have not yet adopted NEC 2005. Therefore, they do not yet require the SCCR marking on panels. However, as stated above, a UL Listed panel installed in that particular state must have an approved SCCR, regardless of the state’s regional requirements.

SCCR FOR CRYDOM SOLID-STATE RELAYS

To date, testing for selected combinations of solid-state relays and fuses performed in an UL approved Schneider Electric Laboratory and witnessed by an UL representative has yielded the results shown in the table(s) below. Current and potential customers of Crydom solid-state relays should note the following:

- Equivalent relays from different manufacturers may not have similar SCCR. Caution is advised when relays are rated in combination with protective devices.
- The following table(s) contains both UL approved and manufacturer approved relay/fuse combinations. The manufacturer approved combinations are highlighted / italicized. The table(s) also contains generic and specific fuse information. Panel builders can use the generic information in their manufacturing procedure. For example, generic information is when protected by a 30Amp Class J Fuse. In these cases, it is allowed to use fuses of the same class with lower ratings.



• Data for a specific manufacturer's fuse (i.e. "when protected by a AJT80 Class J Fuse") was obtained in a manner identical to the procedure for generic information (i.e. "when protected by a $\leq 30\text{A}$ Class J Fuse"). As with the generic evaluation, the specific testing was also witnessed by a UL representative. However, UL does not allow for a SSR to be marked with

a specific manufacturer's fuse. Regardless, the information remains valuable, as it may be used only as a reference to help panel builders better understand the limits of the branch where the specific relay-fuse combination is located. This information will help in determining the panels overall SCCR in cases where the panel is tested as a complete system.

Type	Product Family	Crydom Solid-State Relay Short-Circuit Current Ratings (SCCR)* Suitable for use in a circuit capable of delivering not more than:	
		5kA @ 600Vrms (symmetrical)	100kA @ 600Vrms (symmetrical)
Panel Mount SSR	H12 Series 25A Solid-State Relays, followed by D/CD/W/D, followed by 4825 <u>Additional Products Covered:</u> Series 1 (240/480Vac), H10, and HA/HD relays of the same ratings and construction are represented by Series H12	When protected by: 10Amp Class J fuse OR 10Amp Class CC fuse UL - E116949, Vol. 2	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2
	H12 Series 50A Solid-State Relays, followed by D/CD/W/D, followed by 4850 <u>Additional Products Covered:</u> Series 1 (240/480Vac), H10, and HA/HD relays of the same ratings and construction are represented by Series H12	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2
	CWD4850 / CWA4850	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2
	H12 Series 90A Solid-State Relays, followed by D/CD/W/D, followed by 4890 <u>Additional Products Covered:</u> Series 1 (240/480Vac), H10, and HA/HD relays of the same ratings and construction are represented by Series H12. H12WD4875 also represented in this category	When protected by: 45Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2	When protected by: 100Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2
	H12WD48125 <u>Additional Products Covered:</u> H12D48125, H12CD48125, and CWA24125	When protected by: 50Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 100Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
DIN Rail SSR	CKRD6020 <u>Additional Products Covered:</u> CKRD4820 and CKRD2420	When protected by: 20Amp Class J fuse OR 20Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
	CKRD6030 <u>Additional Products Covered:</u> CKRD4830 and CKRD2430	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
	CMRD6035 <u>Additional Products Covered:</u> CMRD4835 and CMRD2435	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
	CMRD6045 <u>Additional Products Covered:</u> CMRD4845 and CMRD2445	When protected by: 45Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
	CMRD6055 <u>Additional Products Covered:</u> CMRD4855 and CMRD2455	When protected by: 45Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
	CMRD6065 <u>Additional Products Covered:</u> CMRD4865 and CMRD2465	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1	When protected by: 100Amp Class J fuse OR 30Amp Class CC fuse UL - E116950, Vol. 1
Dual SSR	H12D4825D <u>Additional Products Covered:</u> D2425D	When protected by: 20Amp Class J fuse OR 20Amp Class CC fuse UL - E116949, Vol. 2	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2
	H12D4840D <u>Additional Products Covered:</u> D2440D	When protected by: 30Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2	When protected by: 60Amp Class J fuse OR 30Amp Class CC fuse UL - E116949, Vol. 2

*Notes regarding listed SCCR
Models with lower voltage ratings are also represented

www.crydom.com

Models using suffixes are also represented
Class CC fuses are commercially available up to 30A only

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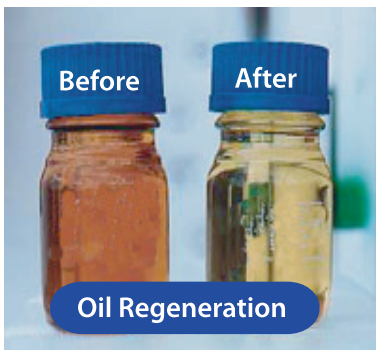
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